Preliminary analysis of the seismic activity recorded at Phalen Colliery, Sydney, Nova Scotia

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by

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Abstract

In collaboration with the Cape Breton Development Corporation (CBDC), the CANMET/MRL Rockburst Group and the Cape Breton Coal Research Laboratory (CBCRL) initiated a project to install a seismic system in the Phalen Colliery. The purpose of this project is to record the seismic activity generated by the expansion of natural gas pockets and breaking of competent rock surrounding the coal layers. The system was installed in November 1993, followed by a period of adjustment. Seismic signals started to be recorded in March 1994.

This report describes the results of the preliminary analysis performed on seismic waveforms recorded between March and September 1994 when an outburst shook the Phalen Colliery (September 28). Waveforms generated by the machine cutting process, blasts, seismic events and the September 28 outburst are analyzed and preliminary results are given. Recommendations to improve the seismic system and subsequent data analysis are also presented.

Keywords

Coal Mines, Seismic activity, seismic networks, outburst

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Analyse préliminaire de l'activité séismique enregistrée à la mine de charbon Phalen, Sydney, Nouvelle-Écosse

par

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Résumé

En collaboration avec la Corporation de développement du Cap Breton, le Groupe de recherche sur les coups de toit et le Laboratoire de recherche sur le charbon du Cap Breton, affiliés aux Laboratoires de recherche minière du CANMET ont initié un projet en vue d'installer un système séismique dans la mine de charbon Phalen. Le but de ce projet est d'enregistrer l'activité séismique générée par l'expansion des poches de gaz à l'avance du front minier ainsi que par la fracturation des roches compétentes autour de la couche de charbon. Le système séismique fut installé en novembre 1993 et une période d'ajustement suivit. L'enregistrement de signaux séismiques débuta en mars 1994.

Ce rapport décrit les résultats de l'analyse préliminaire effectuée sur des ondes séismiques enregistrées entre mars et septembre 1994 lorsqu'un coup de grisou a secoué la mine Phalen, le 28 septembre dernier. Les ondes générées par le processus minier, des sautages, des événements séismiques et le coup de grisou du 28 septembre sont analysées et les résultats préliminaires sont donnés. Certaines recommandations sur des modifications subséquentes au système séismique ainsi que sur l'analyse des données sont aussi présentées.

Mots-clés

Mines de charbon, activité séismique, systèmes séismiques

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1. Introduction

Rock/gas outbursts are relatively rare seismic events in coal mines. They have occurred before in the Sydney coalfield, between 1977 and 1984, at the #26 Colliery (Corbett et al., 1994). As Phalen Colliery workings reached similar depths, a research project was under way in which CANMET were working with the Cape Breton Development Corporation (CBDC), in order to monitor the deepest development drivage, the No. 3 Slope. This project is part of the long term ongoing CBDC-CBCRL Joint Collaborative Research Program. The CANMET/MRL Rockburst Group and the Cape Breton Coal Research Laboratory (CBCRL) initiated a project to install an "intrinsically safe" seismic system in the Phalen Colliery. The purpose of this project is to record the seismic activity generated by stress redistribution and rock movement around the headings, in particular the seismic activity in burst-prone ground.

The seismic monitoring system chosen was the one developed by the CANMET Rockburst Group and installed in several hardrock mines across Ontario and Québec. Major modifications were needed in order to make the system safe enough for the particular conditions encountered in coal mines. The system was installed in November 1993. After a period of adjustment, the modified prototype of the intrinsically safe seismic system began to record seismic waveforms in March 1994.

On September 28, 1994, an outburst occurred at the Phalen Colliery, in No. 3 Slope, injuring one miner, damaging 10 m of roadway and releasing about 1350 m^3 of methane (Forrester, 1994). The successful recording of this event demonstrated the suitability of the data acquisition system used at Phalen and verified the proactive approach taken. This present report shows the preliminary analysis performed on 55 seismic waveforms recorded between March and September 1994. Waveforms generated by the machine cutting process, blasts and some seismic events are analyzed and preliminary results are presented. In particular, all presently available information on the September 28 outburst event data are included. Recommendations for the continuation of the project and the improvement of the seismic system and subsequent data analysis are also presented.

2. Description of the seismic system

As part of the Canada-Ontario-Industry Rockburst Project, CANMET/MRL has developed a remote-controlled seismic system, now operating in five mines in northern Ontario and northwestern Québec (Plouffe et al, 1993). Each system consists in general of five strong-motion triaxial sensors installed in boreholes underground. The system has been modified to perform microseismic monitoring for the Québec mines as well. It is specifically designed to capture complete seismic waveforms to allow the determination of source location as well as seismic source parameters of mining-induced events.

Most processing units where seismic signals are conditioned and passed on to the data acquisition system are located on surface. After the initial signal conditioning and filtering, signals are routed to both the trigger detection controller and the data acquisition board. The signals from each channel are digitized by the data acquisition board at a rate varying from 1024 to 4500 samples per second.

In one Québec mine, like in Phalen Colliery, the processing unit is located underground in a water- and dust-proof case. Phone lines running from surface to the processing unit allow for file transfer and remote setting of data acquisition parameters.

2.1 Data acquisition system

In the past, high speed data acquisition required expensive, highly powerful computers. With the technological advances made by the computer industry, it is now more cost-effective to use microcomputers to perform this task. Although high speed data acquisition hardware is now available, most software packages available operate under the operating system DOS, which lacks the flexibility and power of multi-tasking operating systems. CANMET has opted for the QNX™ (© Quantum Software Systems Ltd.) operating system which allows the data acquisition to be made up of several smaller tasks running concurrently on a priority basis. Tasks not requiring immediate processing can be put on hold so they do not compete for processor time.

Remote access to the system is also possible, simply by having a communication task run in the background, which requires minimal processor time.

The data acquisition software consists of three main modules: primary and secondary acquisition programs and a demultiplexer program. A configuration program, a start batch file and a stop batch program complete the package. Optional program modules are also available to display waveforms and simulate events under software control.

The start batch file initiates the acquisition process by starting the primary acquisition task, which performs all executive functions including creating the secondary acquisition task and the demultiplexer task, which run at lower priorities. The primary acquisition module reads in parameters from the configuration file on disk and then performs a complete hardware and software initialization. It is also responsible for detecting, storing and queuing events in memory. The secondary acquisition module is responsible for transferring the acquired events from the memory buffers to the hard disk storage.

A sophisticated triggering controller has also been developed to eliminate the recording of very small seismic events, machine noise or electrical spikes which could saturate the system. The controller has the following features: selectable trigger windows, selectable number of channels for a valid trigger, short-term integration for spike suppression, selectable trigger threshold, individual channel enable/disable switches, event simulator to test the trigger controller, software enable/disable of the triggering, optional hardware-selectable retrigger timer and optional sensor amplifier gain control. If the trigger controller determines that a valid event has occurred, then two seconds approximately of seismic data are stored for each channel, including half a second of pre-trigger data.

2.2 Waveform analysis

The CANMET waveform analysis software is used to calculate seismic parameters of mining-induced seismic events, to locate these events, to estimate their size and or for other research purposes.

The waveforms can be displayed in acceleration, velocity and displacement modes. Peak particle acceleration and velocity can be determined and used for damage assessment. Waveforms can be rotated in order to obtain transverse and radial waveforms for polarization studies and, for source parameter studies, primary (P) and shear (S) waves are also available. Mine operators can be provided with seismic energy and equivalent magnitude values in order to quantify the size of the seismic events, as well as source locations. Double-couple focal mechanisms can also be analyzed.

In the frequency domain, corner frequencies and low-frequency spectral density levels allow the determination of source radius, seismic moment and stress drop values.

Currently, new additions to the software under development include automation of seismic parameters computations, polarization analysis, considering surface and mined zone effects, raypath analysis, attenuation, non-double-couple focal mechanisms and near-field/far-field analysis.

All these parameters provide information to the mine operators about the nature, location, frequency and other characteristics of seismic activity originating from their mines. The data could then be included in the planning of mine support and development systems.

2.3 System modifications

In order to produce an intrinsically safe system for coal mines, the seismic system was modified to address several conditions (Corbett et al, 1994):

- The sensors had to be installed near the emission source, preferably ahead of the development face, in order to alleviate attenuation effects (decrease in signal frequency and amplitude);
- The system had to be highly mobile to move with the cutting machine, portable and compatible with existing coal mine equipment; and able to operate continuously, be remote-controlled and have an intelligent triggering mechanism;
- All components had to be intrinsically safe for use in hazardous environment and rugged enough to operate in demanding coal mine conditions.

The prototype installed in November 1993 at Phalen Colliery is essentially a full waveform system recording signals from five triaxial sensors similar to those used in Québec or Ontario, but modified to fulfil the above conditions. The five sensors are located on a same plan across the No. 3 slope. All of its components are intrinsically safe according to appropriate regulations. It is certified by NRCan and is approved by the Coal Mining Safety Commission. Although, the data acquisition procedure is similar to the aforementioned system; the sampling rate could be varied between 600 and 20000 samples per second per channel. Further information about the system is given by Corbett et al. (1994).

2.4 Problems encountered

Following the installation of the seismic system modified for Phalen Colliery, some "teething" problems occurred as the prototype system encountered some difficulties of adaptation to the coal mine environment. Between November 1993 and March 1994, several practical problems required a considerable amount of time to be solved. This refrained the system from being able to record data efficiently. Also, delays were generated by the certification of components of the seismic system, specially the power supply.

A triggering problem in the preamplifiers was detected early on. In its original design, the pre-amplifier/sensor component needed a 28 V voltage input in order to operate properly. In order to accelerate the process of certification of the system, modifications were made to the

preamplifiers, consisting of breaking their electrical isolation, so that they can function with a lower voltage of about 18 V. Numerous false triggers occurred following the operation of the these modified preamplifiers. A 2-month delay occurred when further modifications became necessary to bring the voltage from 18 V to 24 V. Clearly, the 18 V voltage was too close to the very low end of the working voltage range of for the preamplifier/sensor component. Meanwhile, in order to alleviate this problem, the gains of the sensors were decreased.

The problem of false triggers still persisted after the above modifications. The breakage of the isolation of the preamplifiers in order to reduce the input voltage needed seems to have made them sensitive to ground loops, electrical spike, etc. Corrective measures have been taken.

After these problems were circumvented, one main concern remained: the decreasing number of operational sensors. On September 28, when the outburst occurred, only one accelerometer was operational. The factors contributing to this situation are related to the sensor installation procedure at the mine. Indeed, the retrieval of the malfunctioning sensors revealed to be impossible due to ground problem, and the isolation problem of the preamplifiers. Careful supervision of these components should prevail in the future to avoid future reoccurrence.

3. Data recorded

Following the September 28, 1994, outburst, ongoing analysis of the data recorded was accelerated in order to define preliminary trends or patterns of seismicity at Phalen. For the period between March and September 1994, 55 files, were recorded and analyzed (Appendix A). Of these, 27 files (49%) were generated by electrical spikes and were thus rejected (in Appendix B, some of these electrical spikes are shown). For the remaining 28 files (51%), identification was facilitated by the information provided by Phalen Colliery employees to CBCRL personnel; five separated classes were formed:

- Twelve files were due to the machine cutting process;
- Six files were caused by blasting;

- Two files were known seismic events, including the September 28 outburst;
- Three files corresponded to test hammer strikes on the mine wall.

Five of the files had an unknown origin.

4. Observational analysis

The 28 signal files were analyzed using the CANMET waveform analysis software. Unfortunately, sensors locations have not yet been surveyed because of the debris following the outburst. The information on coordinates of the sensors is required in order to proceed furthermore with distance-related source parameters, such as source location and magnitude.

The waveforms recorded by the system are shown in Appendix B. The observations are summarizes below in relation to the five types of seismic events. All types of events show their characteristic signature. In the time domain, the signature of the waveforms for different types of seismic events was examined. This includes parameters such as the dominant frequency range, the presence of frequency peaks and the ratio signal/noise of different types of event in the frequency domain.

Hammer strikes

Due to the closeness of the source, most hammer strike files show signal saturation. P- and S-wave arrivals are, however, clearly visible. In the frequency domain, a wide range of energy is observed with a concentration in the 50-400 Hz frequency range. A peak was observed at 110 Hz and 150 Hz for sensors 1 and 2 respectively.

Machine cutting

These events are similar to the high-amplitude background noise. In the frequency domain, the background noise is very close to the signal. The range of energy is not as wide as in the

previous case, and was mainly limited to the 100-500 Hz frequency range. A very clear peak is observed in the 100-120 Hz range for sensor 3. Another peak is observed in the 220-260 Hz range in most of the case.

Blasts

The recorded bandwidth for the blasts is clearly wide, as for hammer strikes, with a concentration of energy between 10 Hz and 500 Hz. A peak is observed around 100 Hz for sensor 3 and there is a large separation between the background noise and the signal due to the large energy content of the blasts.

Seismic events

The 100 Hz peak is still observable but is smaller for the seismic events for which the frequency bandwidth is the largest, 80 to 1000 Hz. For the September 16 event, there are some small visible "aftershocks". The September outburst is discussed in the section 5.

Events of unknown origin

These events seem to be similar to those generated by the machine cutting process: similar frequency range, similar 100-150 Hz range energy concentration, and 250 Hz peak. However, the noise/signal ratio is smaller for these events.

5. The September 28 outburst

As was the case for the other seismic event, the September 28 outburst showed the 100 Hz peak and the frequency bandwidth is large, 80 Hz to 1000 Hz. However, the separation between the background noise and the signal is not clearly visible because there was some machine cutting going on at the time of the outburst.

The time window of the recorded event file is about 0.7 second, of which, the outburst lasts for about 60 milliseconds. The following portion of the window, of unknown origin, shows a good separation in the 50 to 500 Hz range between the background noise and the signal. Its recorded time length is about 0.5 second. It generated about 10 times the seismic energy generated by the outburst.

Due to the existing uncertainties about the gains of the sensors and the preamplifiers at the time of the outburst, further analysis could not proceed. Comparison between the outburst and other mining induced seismic events cannot be made unless such basic information becomes available.

6. Conclusions

The design of the prototype seismic monitoring system installed in Phalen Colliery has fulfilled the main objectives of the project. Beside being intrinsically safe, the characteristics of the data acquisition system such as the frequency range of monitoring and recording parameters proved to be adequate for Phalen. The serious rock/gas outburst on September 28, 1994, was recorded although only one sensor was operational at that time; investigation will be pursued about the cause of the situation.

The different types of events recorded at Phalen show different signatures, allowing for a strategy to be developed for event classification in situ. Further improvements are required in different areas: design of the sensor array, communications between different parties involved with regards to the performance of the system and exchange of information. The present waveform analysis shows clearly the potential benefit of the seismic data processing for further in-depth analysis of causes of occurrence of seismic events, including outbursts, at Phalen.

7. Recommendations

According to this preliminary analysis, discrimination of different types of event from their seismic signals is feasible. Some recommendations are provided here to increase the efficiency

of any future analysis and the response provided to CBDC and Phalen Colliery personnel.

A process for routine analysis of Phalen data will be implemented, as soon as possible, in order to increase the speed of the response provided to all the concerned parties. This routine analysis will also provide information on the system status: sensors malfunctions or losses, cable breaks, etc. Interactions between all parties in order to maintain the system fully operational should then greatly increase the quality of the response provided. The continued help of the experienced Colliery personnel with CANMET staff in the set up of the sensor array (i.e. borehole drilling and sensor installation) and maintaining electrical cables is required to make this experience a successful one. This help could optimize the operation status of the seismic system, regarding sensors and electrical cables.

An ideal array configuration should include some sensors in front of the development face. This requirement is very difficult, if not impossible, to achieve in practice. A new design of array configuration is, however, needed to improve the accuracy of source location and seismic parameters determinations. The number of sensors should also be increased to provide a better coverage and analysis of seismic activity. These matters are currently under consideration.

Surveying the borehole/sensor locations (determination of location and orientation of the sensors) and maintaining an up-to-date logbook of all the changes made during the data acquisition period are required for any in-depth analysis of recorded signals. An increase of the length of the pre-trigger window will eliminate the possibility of data loss because of system trigger on S-waves instead of P-waves.

It would be interesting to investigate the origin of the 100 Hz frequency observed in several classes of seismic files (the source, the medium or some kind of resonance of the support (rib)).

8. Acknowledgements

The full cooperation and assistance provided by the personnel of the CBCRL, specially, Mr.

G.R. Corbett, Dr. P. Cain and Dr. D.J. Forrester is gratefully acknowledged. The authors would like also to thank the management and the personnel of the Phalen Colliery for their collaboration.

9. References

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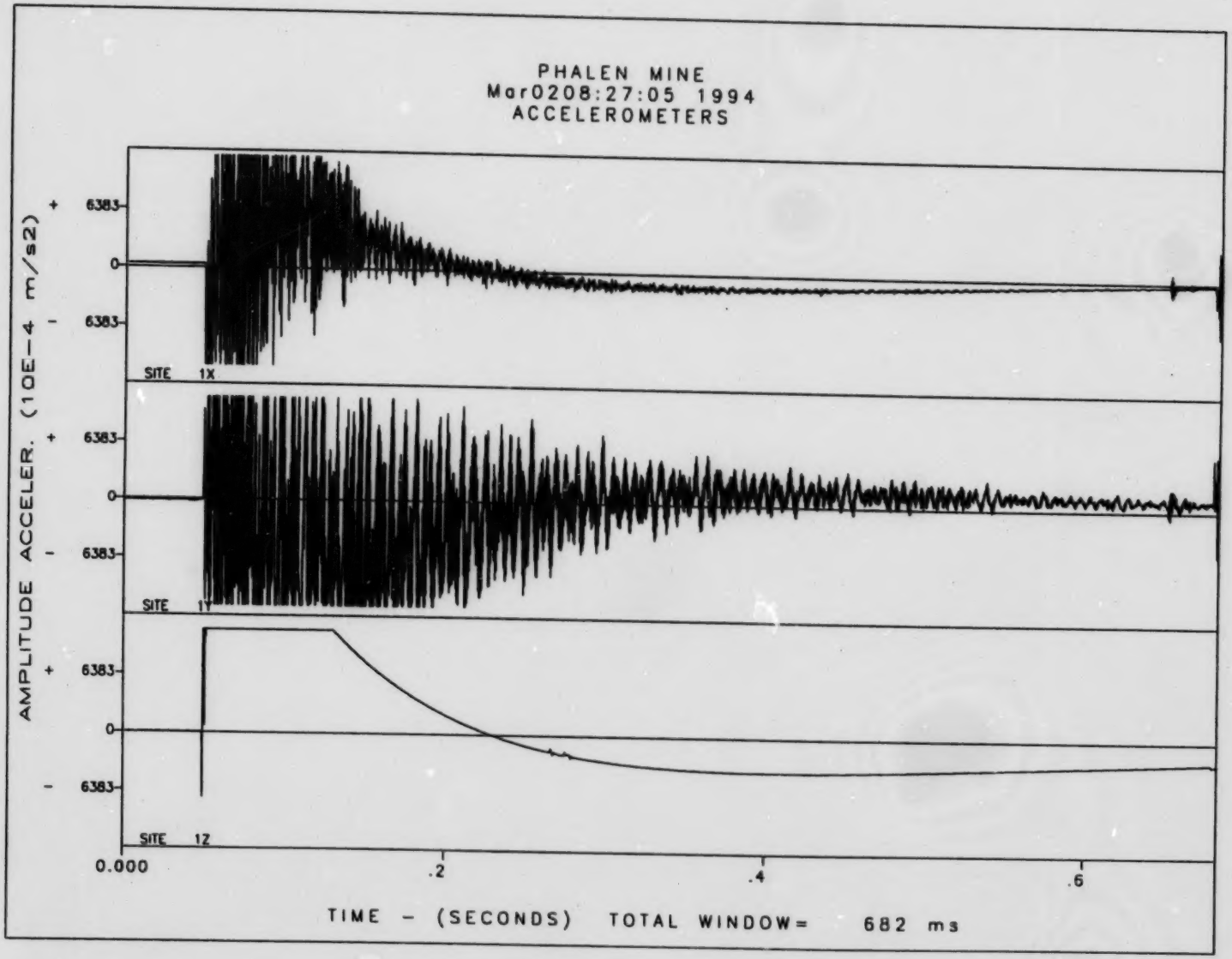
Appendix A: List of the seismic files analyzed

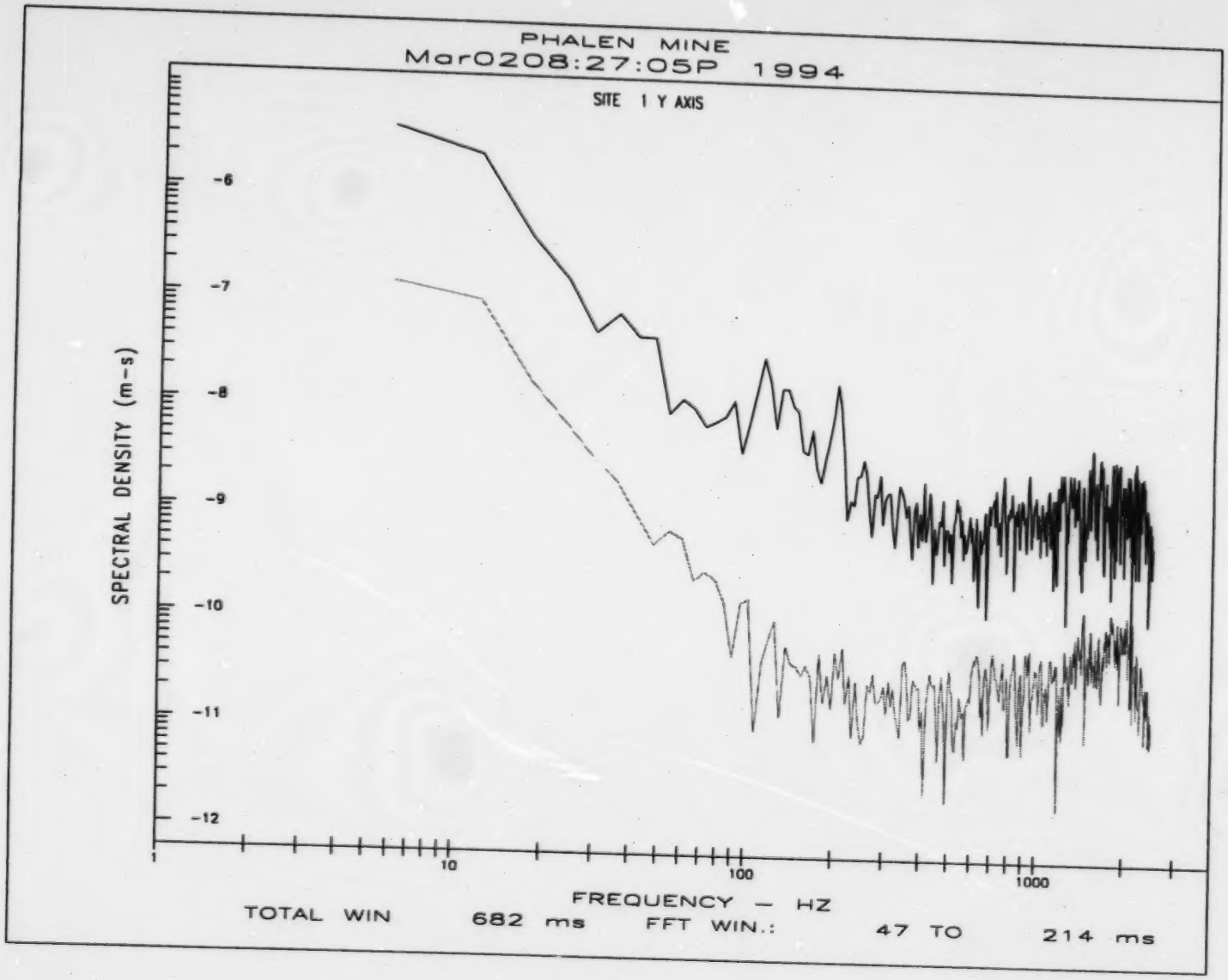
File name	Date of recording	Time of recording	Class
Mar0208:27:05	March 02	08:27:05	Unknown
Mar0208:45:05	March 02	08:45:05	Unknown
Mar0208:45:10	March 02	08:45:10	Unknown
Mar0208:45:12	March 02	08:45:12	Spike
Mar0208:45:15	March 02	08:45:15	Spike
Mar0208:55:05	March 02	08:55:05	Unknown
Mar0208:55:16	March 02	08:55:16	Spike
Mar0209:21:02	March 02	09:21:02	Hammer
Mar0209:22:05	March 02	09:22:05	Hammer
Mar0408:47:19	March 04	08:47:19	Spike
Mar0410:35:02	March 04	10:35:02	Spike
Mar0813:45:48	March 08	13:45:48	Spike
Mar1712:37:27	March 17	12:37:27	Spike
Mar1712:38:01	March 17	12:38:01	Spike
Mar1713:30:58	March 17	13:30:58	Spike
Mar1713:33:00	March 17	13:33:00	Spike
Mar2308:00:31	March 23	08:00:31	Spike
Mar2308:00:37	March 23	08:00:37	Spike
Mar2308:01:04	March 23	08:01:04	Spike

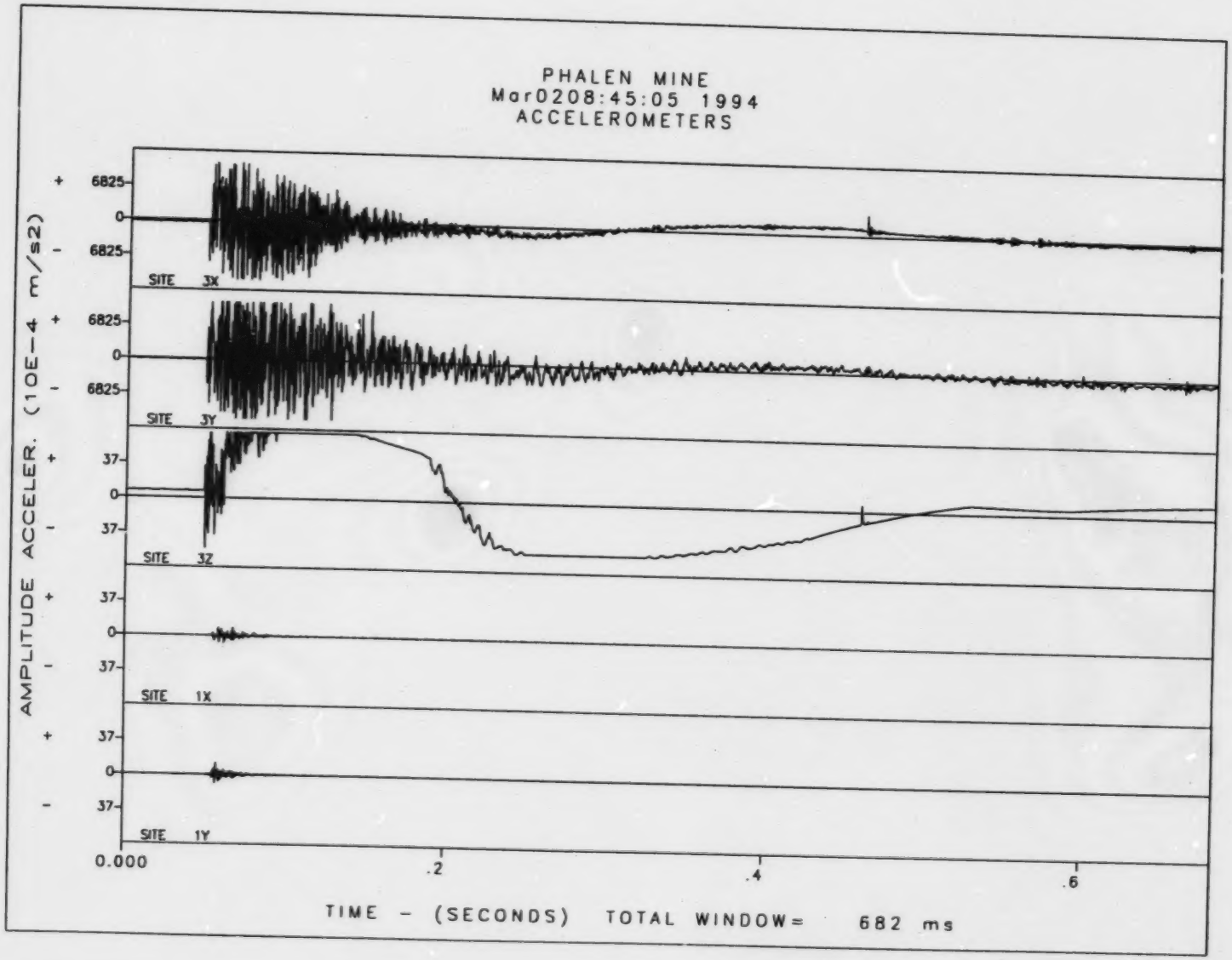
Mar2308:01:20	March 23	08:01:20	Spike
Mar2308:01:37	March 23	08:01:37	Spike
Mar2311:52:18	March 23	11:52:18	Spike
Mar2312:41:26	March 23	12:41:26	Spike
Mar2312:55:36	March 23	12:55:36	Spike
Mar2312:58:41	March 23	12:58:41	Spike
Mar2313:15:39	March 23	13:15:39	Spike
Mar2313:35:59	March 23	13:35:59	Spike
Mar2313:37:59	March 23	13:37:59	Spike
Mar2516:21:15	March 25	16:21:15	Spike
Jun1412:59:36	June 14	12:59:36	Spike
Jun2109:04:50	June 21	09:04:50	Hammer
Jul1120:09:04	July 11	20:09:04	Machine cutting
Jul1120:38:29	July 11	20:38:29	Machine cutting
Jul1120:38:34	July 11	20:38:34	Machine cutting
Jul1120:59:17	July 11	20:59:17	Machine cutting
Jul1120:59:22	July 11	20:59:22	Machine cutting
Jul1120:59:30	July 11	20:59:30	Machine cutting
Jul1120:59:35	July 11	20:59:35	Machine cutting
Jul1120:59:53	July 11	20:59:53	Machine cutting
Jul1121:00:03	July 11	21:00:03	Machine cutting

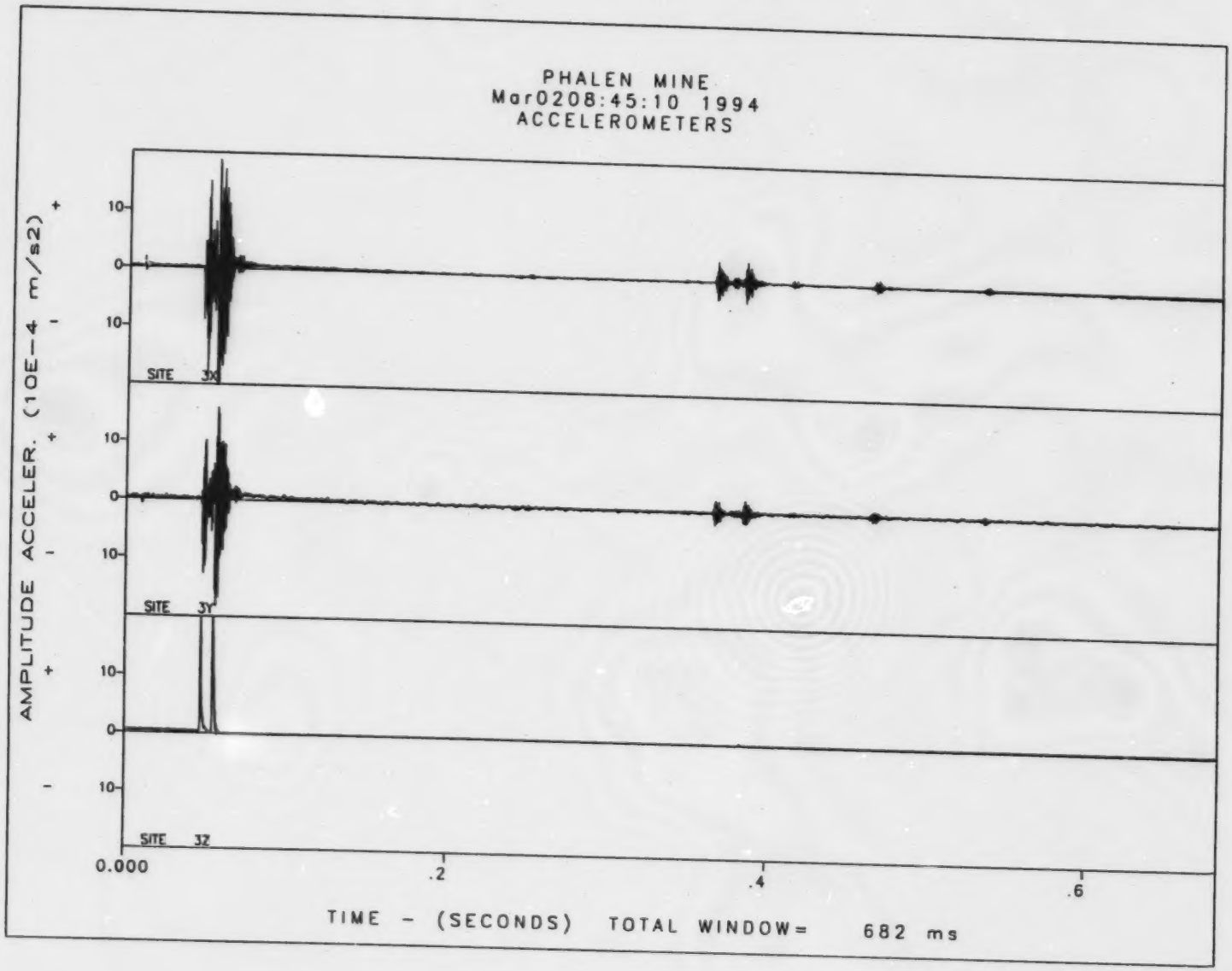
Jul1121:00:19	July 11	21:00:19	Machine cutting
Jul1121:00:24	July 11	21:00:24	Machine cutting
Jul1121:00:27	July 11	21:00:27	Machine cutting
Jul1911:26:38	July 19	11:26:38	Spike
Sep1510:32:19	Sept 15	10:32:19	Blast
Sep1603:45:47	Sept 16	03:45:47	Unknown
Sep1622:31:57	Sept 16	22:31:57	Seismic event
Sep2008:01:44	Sept 20	08:01:44	Blast
Sep2108:23:42	Sept 21	08:23:42	Blast
Sep2207:57:22	Sept 22	07:57:22	Spike
Sep2208:12:43	Sept 22	08:12:43	Blast
Sep2208:51:38	Sept 22	08:51:38	Spike
Sep2308:02:08	Sept 23	08:02:08	Blast
Sep2309:23:48	Sept 23	09:23:48	Blast
Sep2808:45:20	Sept 08	08:45:20	Outburst

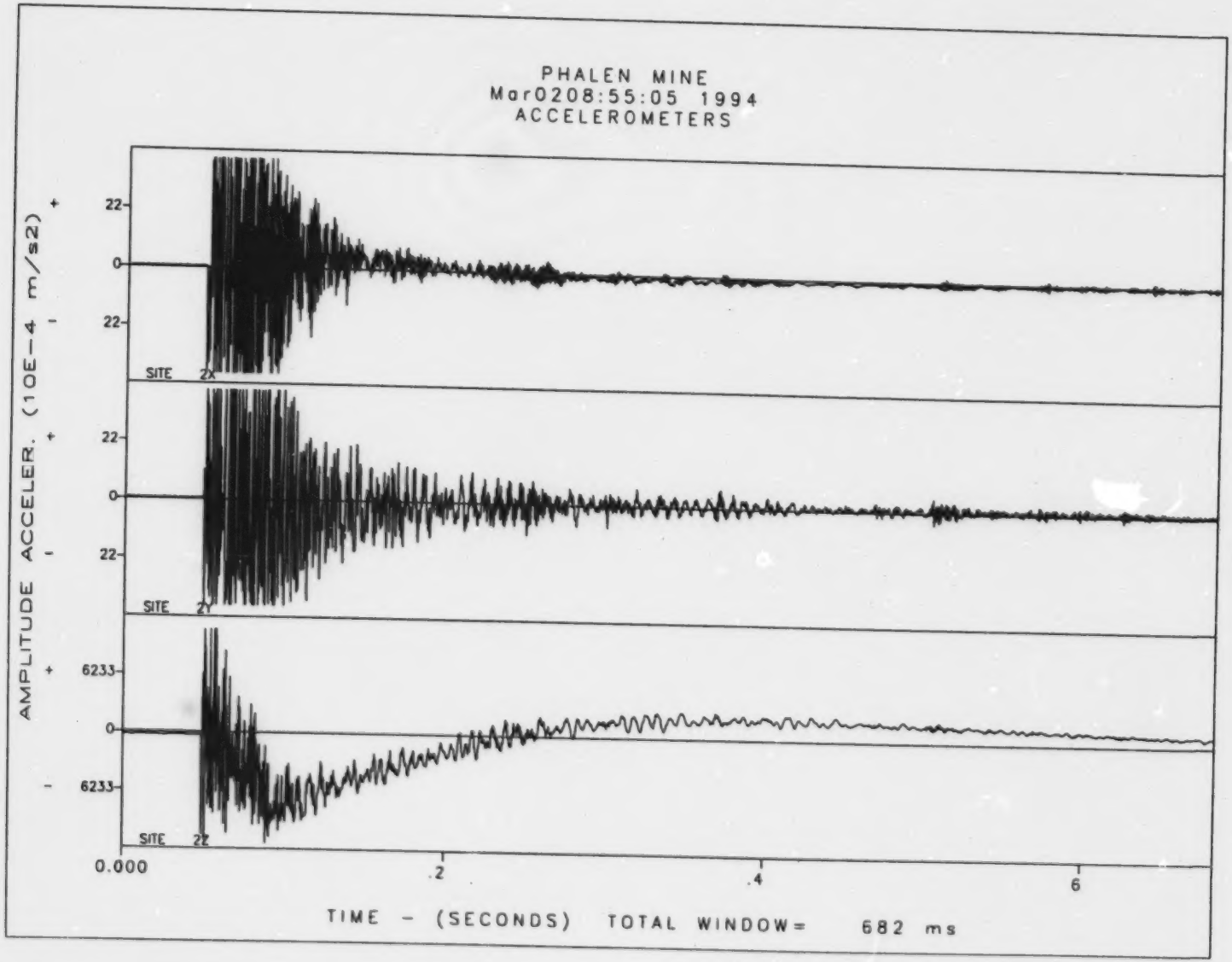
Appendix B: Waveform and Spectra

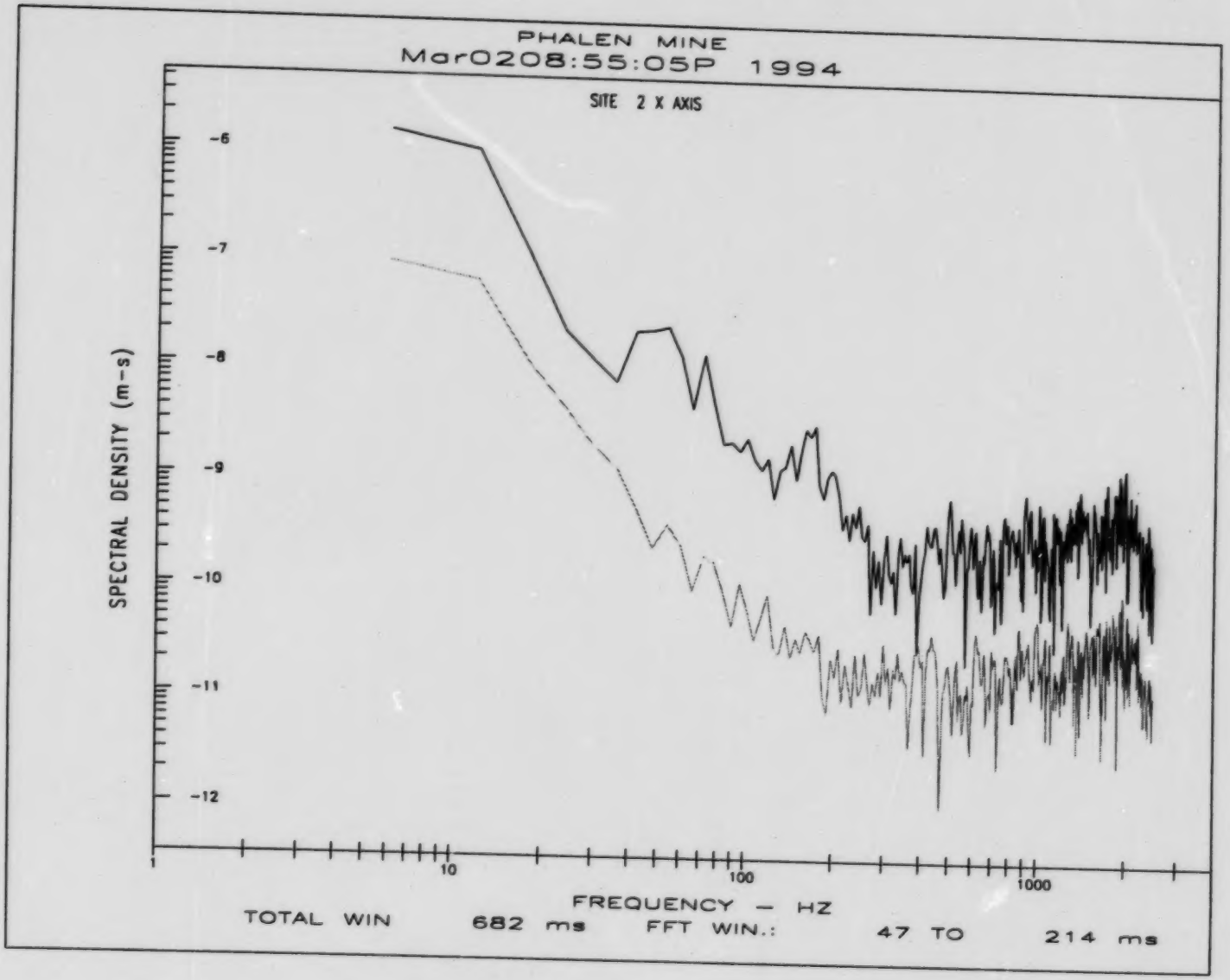

PHALEN MINE
Mar0208:27:05 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+ 6383
0
- 6383
SITE 1X
+ 6383
0
- 6383
SITE 1Y
+ 6383
0
- 6383
SITE 1Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

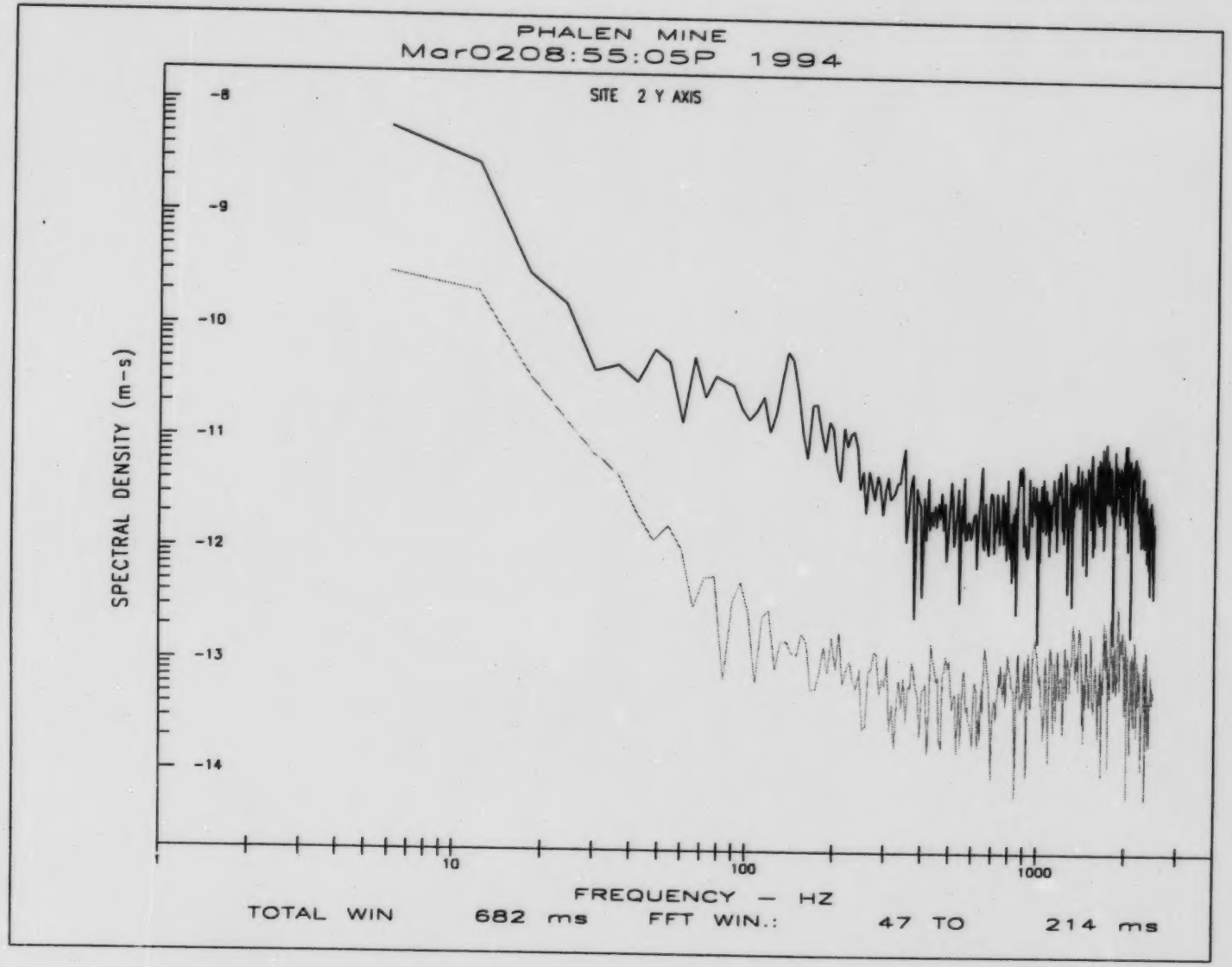

PHALEN MINE
Mar0208:27:05P 1994
SITE 1 Y AXIS
SPECTRAL DENSITY (m-s)
-6
-7
-8
-9
-10
-11
-12
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 47 TO 214 ms

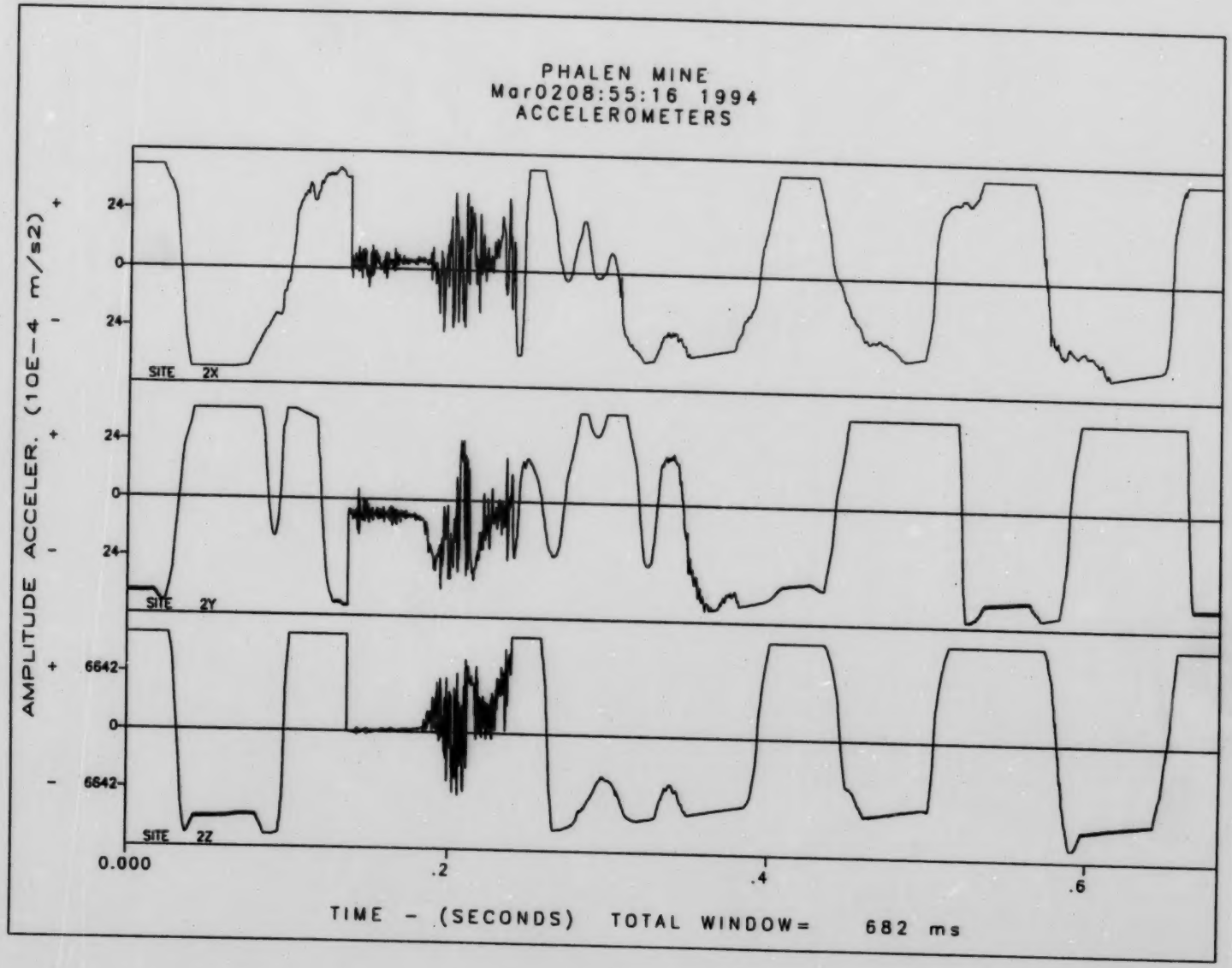

PHALEN MINE
Mar0208:45:05 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+ 6825
0
- 6825
SITE 3X
+ 6825
0
- 6825
SITE 3Y
+ 37
0
- 37
SITE 3Z
+ 37
0
- 37
SITE 1X
+ 37
0
- 37
SITE 1Y
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

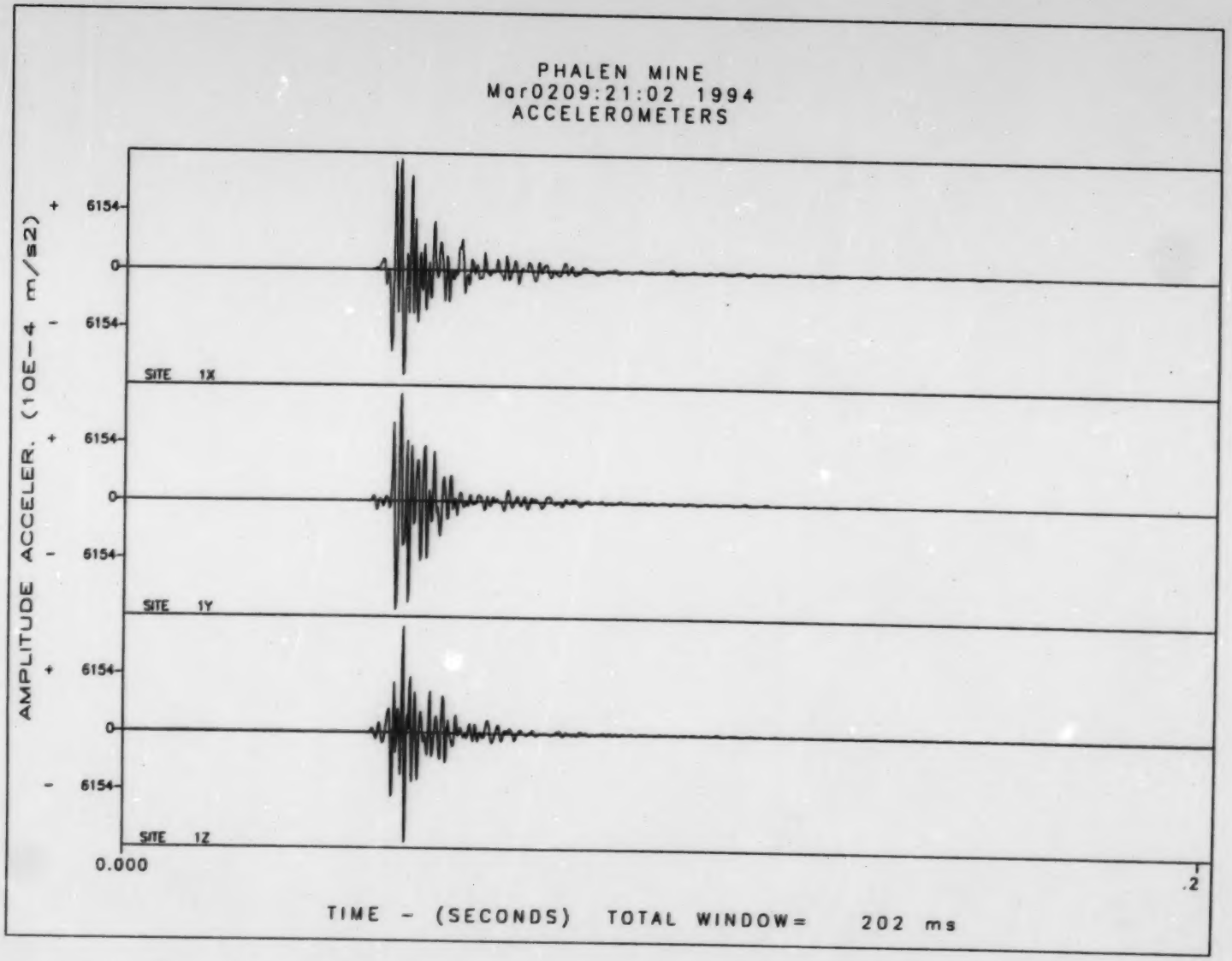

PHALEN MINE
Mar0208:45:10 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+
-
10
0
10
SITE 3X
10
0
10
SITE 3Y
10
0
10
SITE 3Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

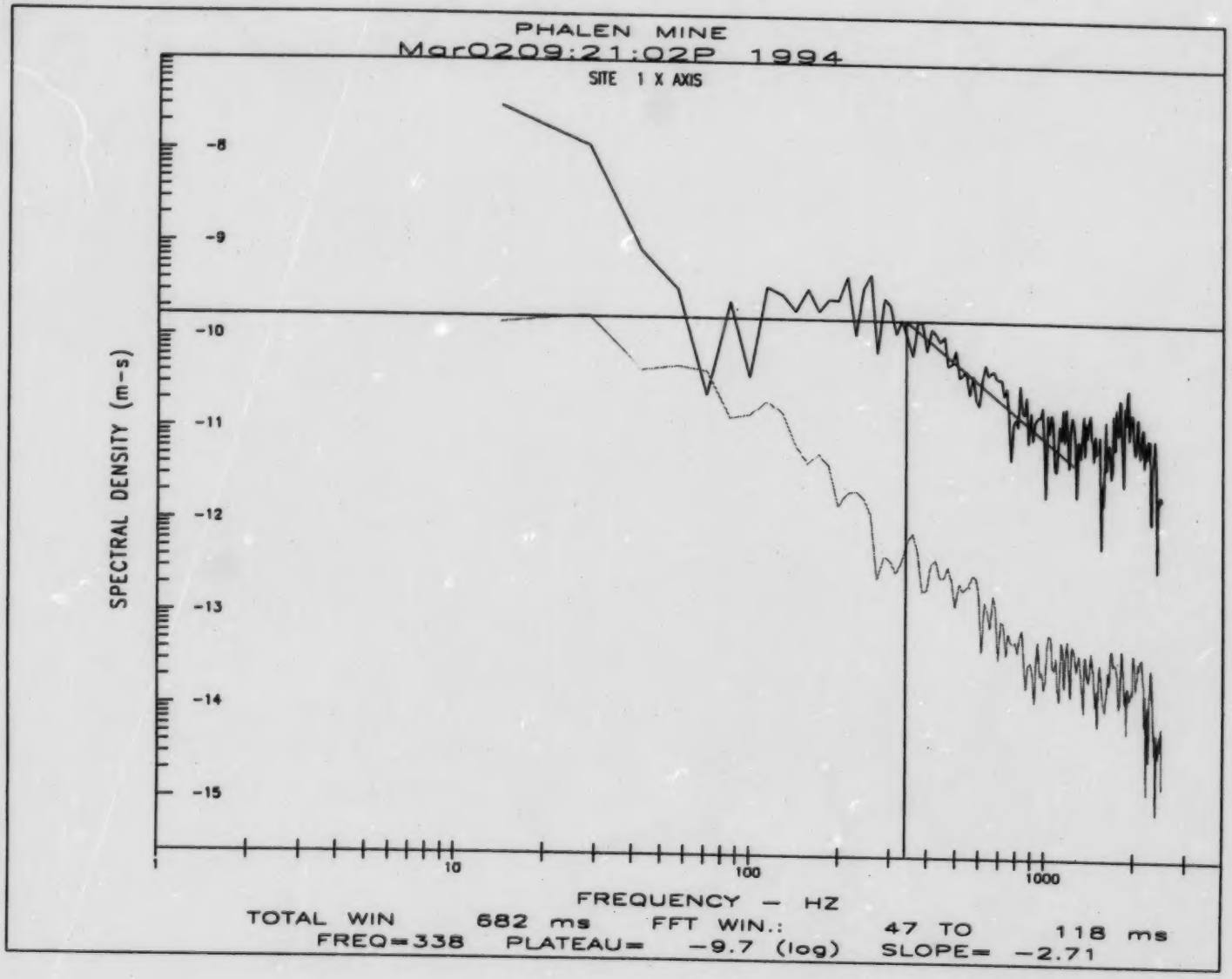

PHALEN MINE
Mar0208:55:05 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+
22
0
22
-
SITE 2X
+
22
0
22
-
SITE 2Y
+
6233
0
6233
-
SITE 2Z
0.000
.2
.4
6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

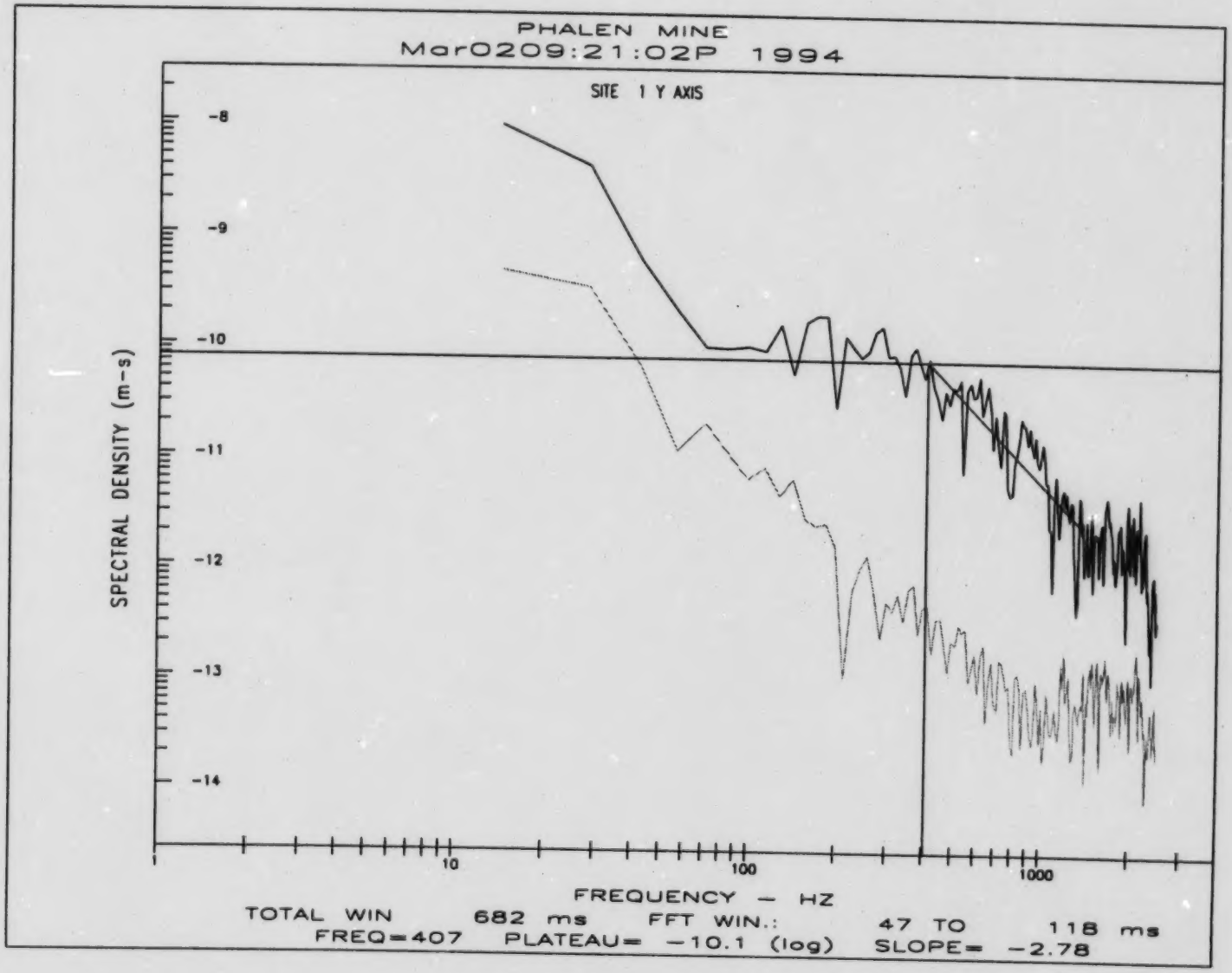

PHALEN MINE
Mar0208:55:05P 1994
SITE 2 X AXIS
SPECTRAL DENSITY (m-s)
-6
-7
-8
-9
-10
-11
-12
1
10
100
1000
FREQUENCY - HZ
TOTAL WIN 682 ms FFT WIN.: 47 TO 214 ms

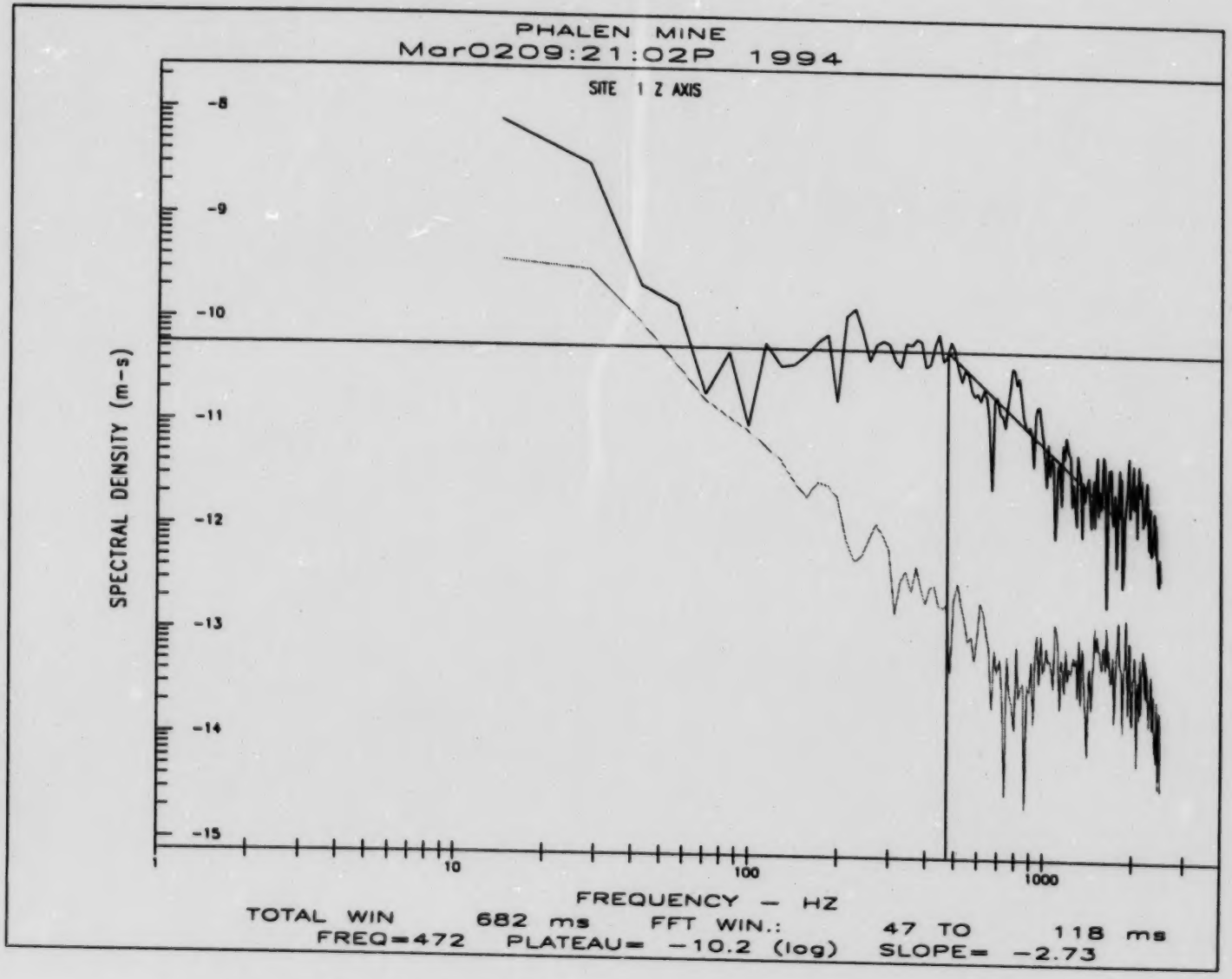

PHALEN MINE
Mar0208:55:05P 1994
SITE 2 Y AXIS
SPECTRAL DENSITY (m-s)
-8
-9
-10
-11
-12
-13
-14
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 47 TO 214 ms

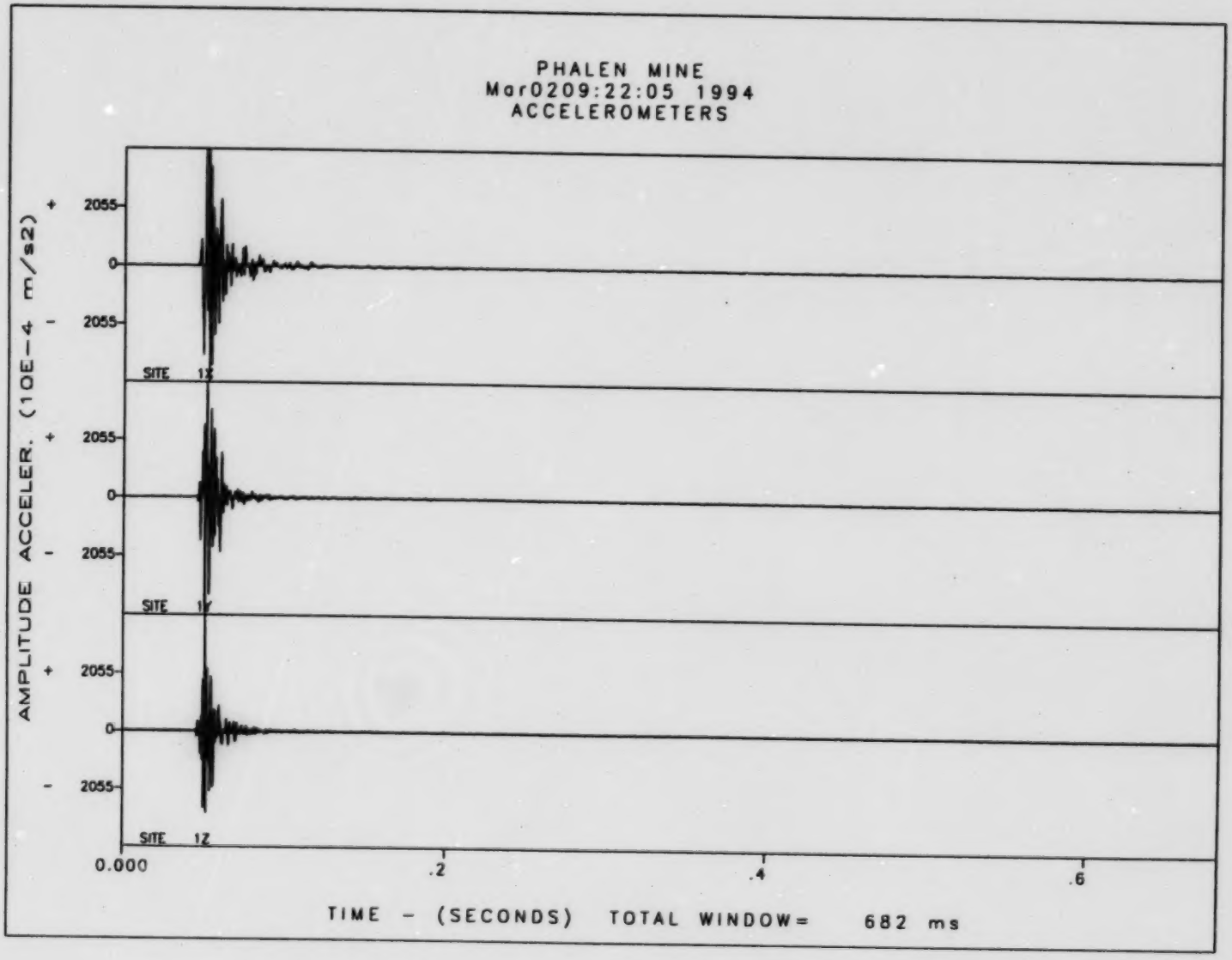

PHALEN MINE
Mar0208:55:16 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+
-
24
0
24
SITE 2X
+
-
24
0
24
SITE 2Y
+
-
6642
0
6642
SITE 2Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

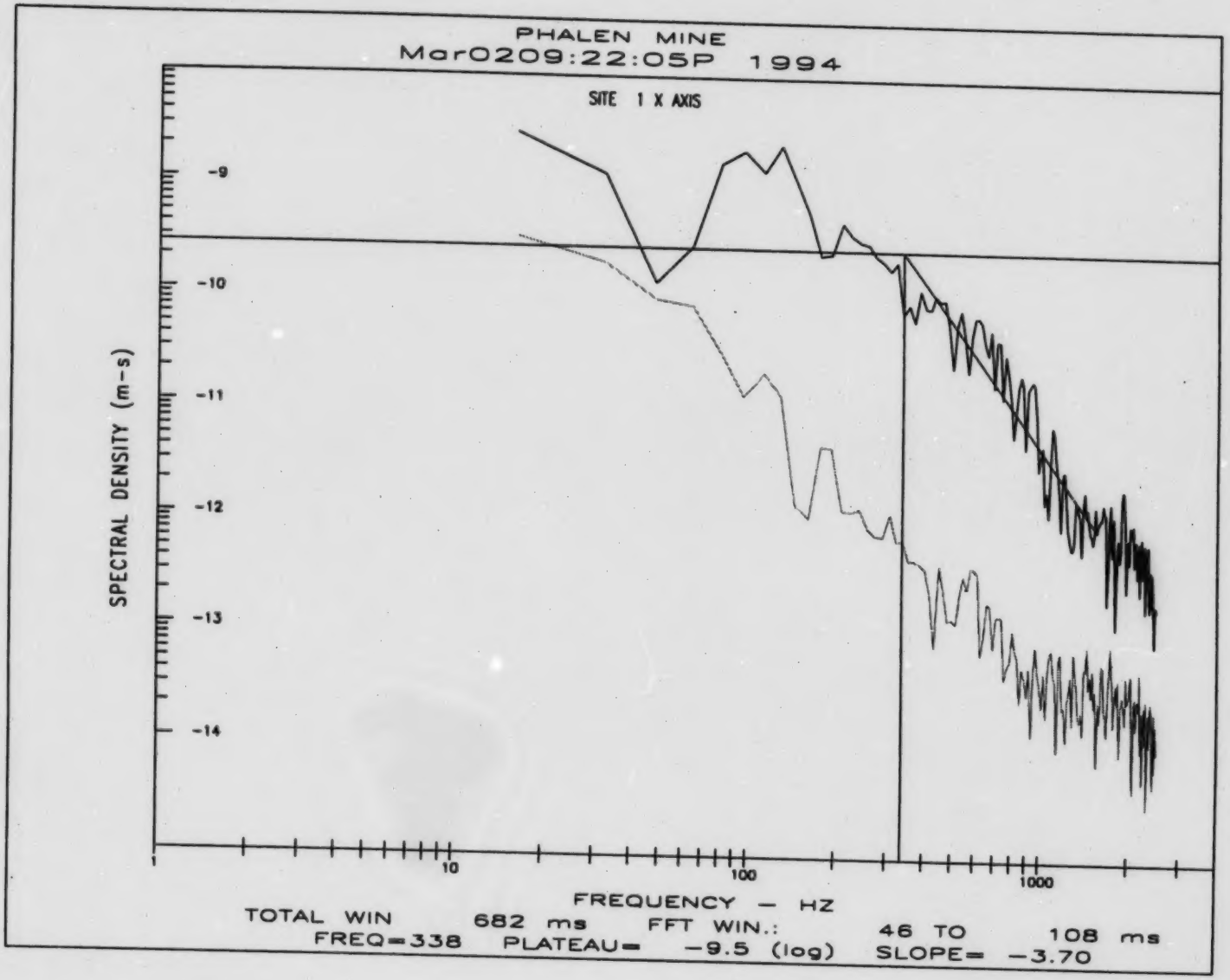

PHALEN MINE
Mar0209:21:02 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+ 6154
0
- 6154
SITE 1X
+ 6154
0
- 6154
SITE 1Y
+ 6154
0
- 6154
SITE 1Z
0.000
.2
TIME - (SECONDS) TOTAL WINDOW= 202 ms

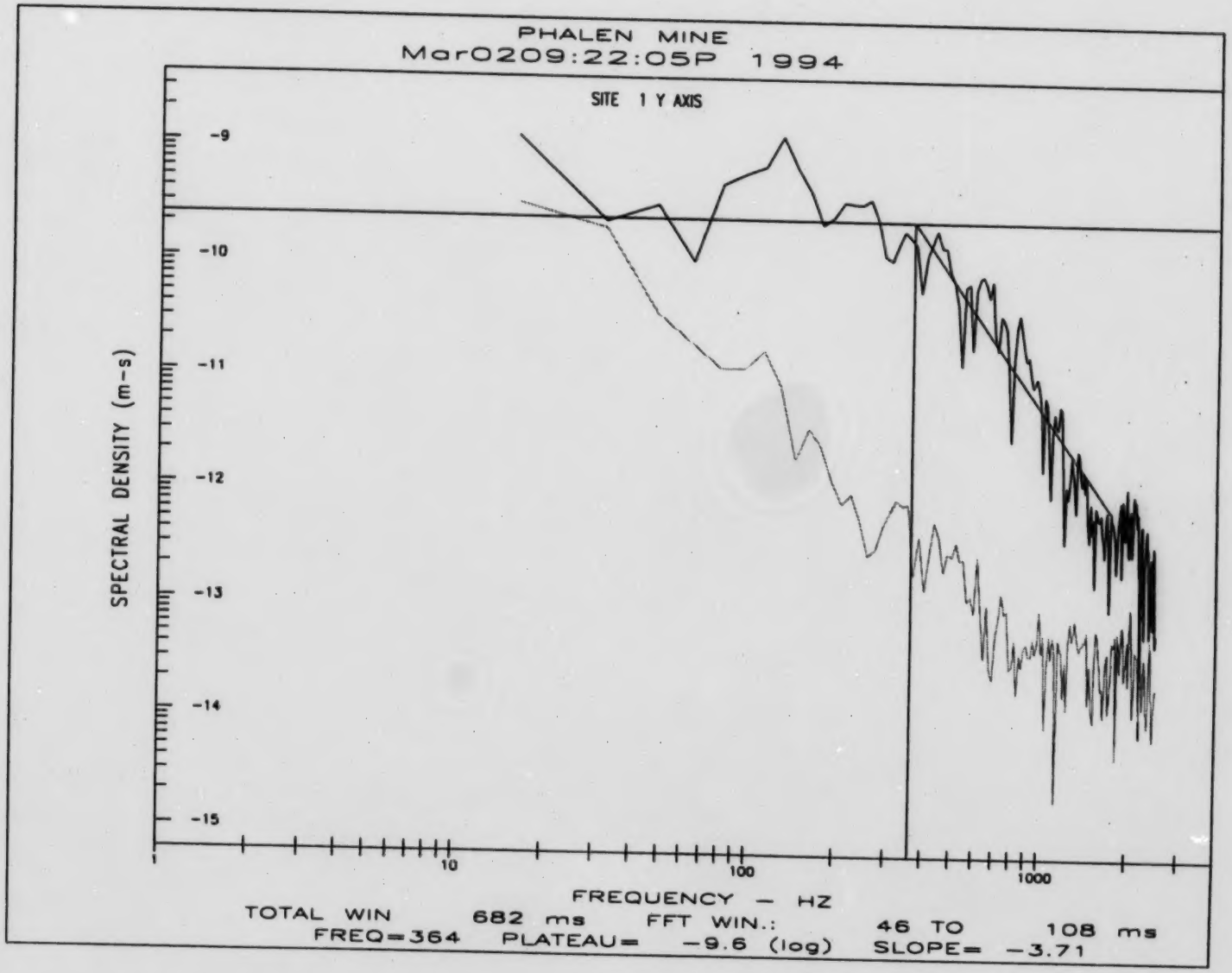

PHALEN MINE
Mar0209:21:02P 1994
SITE 1 X AXIS
SPECTRAL DENSITY (m-s)
-8
-9
-10
-11
-12
-13
-14
-15
1
10
100
1000
FREQUENCY - HZ
TOTAL WIN 682 ms FFT WIN.: 47 TO 118 ms
FREQ=338 PLATEAU= -9.7 (log) SLOPE= -2.71

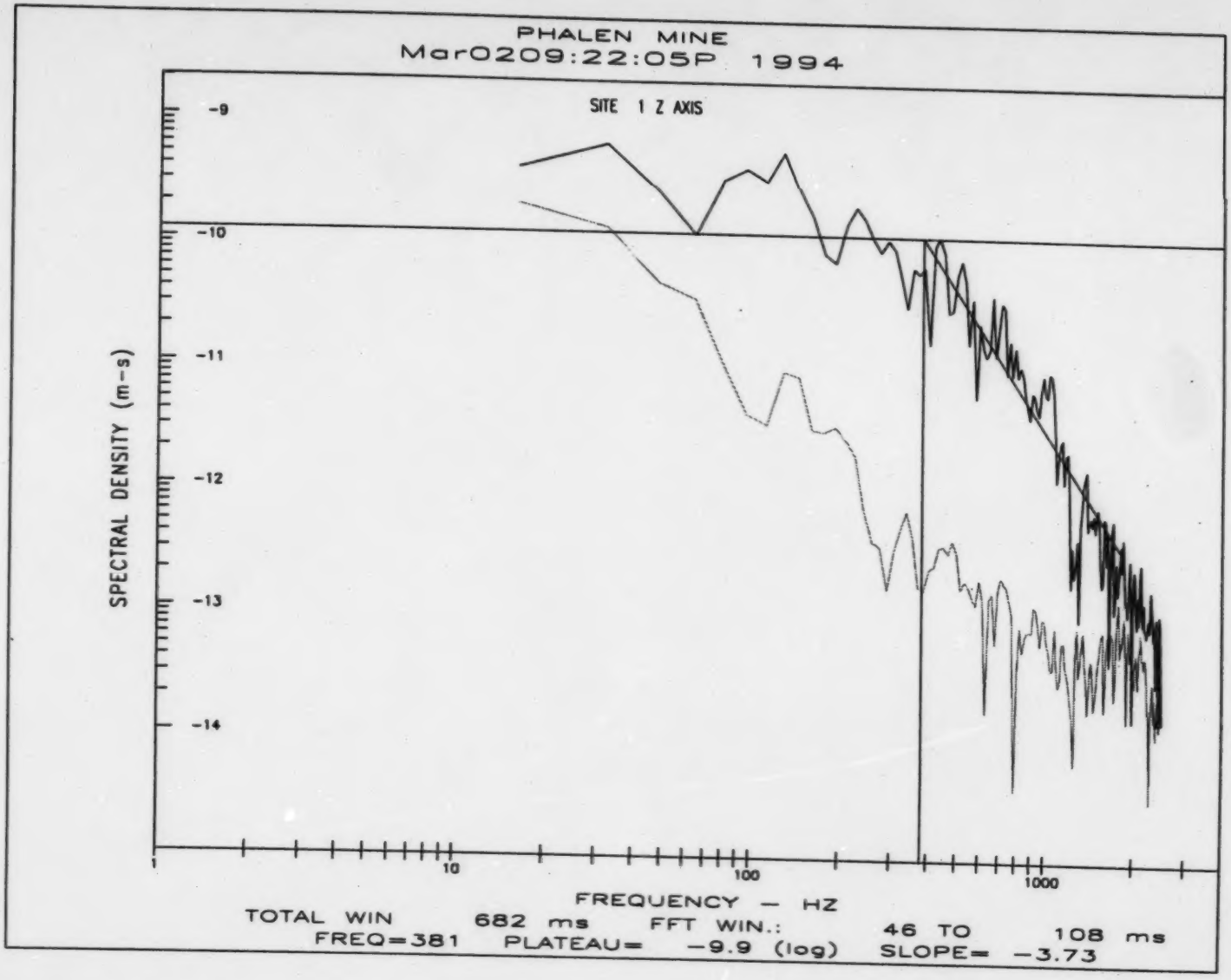

PHALEN MINE
Mar0209:21:02P 1994
SITE 1 Y AXIS
SPECTRAL DENSITY (m-s)
-8
-9
-10
-11
-12
-13
-14
10
100
1000
FREQUENCY - HZ
TOTAL WIN 682 ms FFT WIN.: 47 TO 118 ms
FREQ=407 PLATEAU= -10.1 (log) SLOPE= -2.78

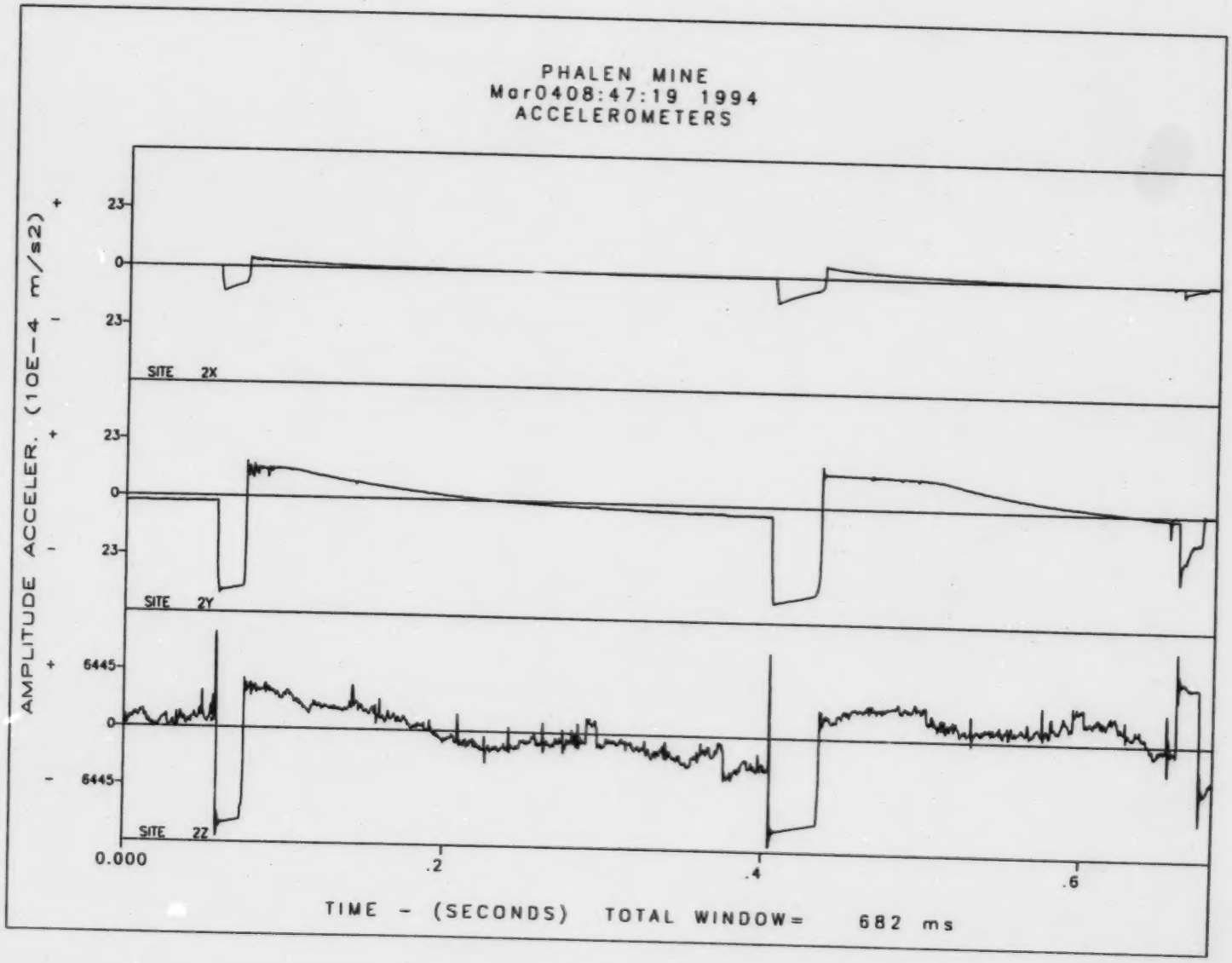

PHALEN MINE
Mar0209:21:02P 1994
SITE 1 Z AXIS
SPECTRAL DENSITY (m-s)
-8
-9
-10
-11
-12
-13
-14
-15
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 47 TO 118 ms
FREQ=472 PLATEAU= -10.2 (log) SLOPE= -2.73

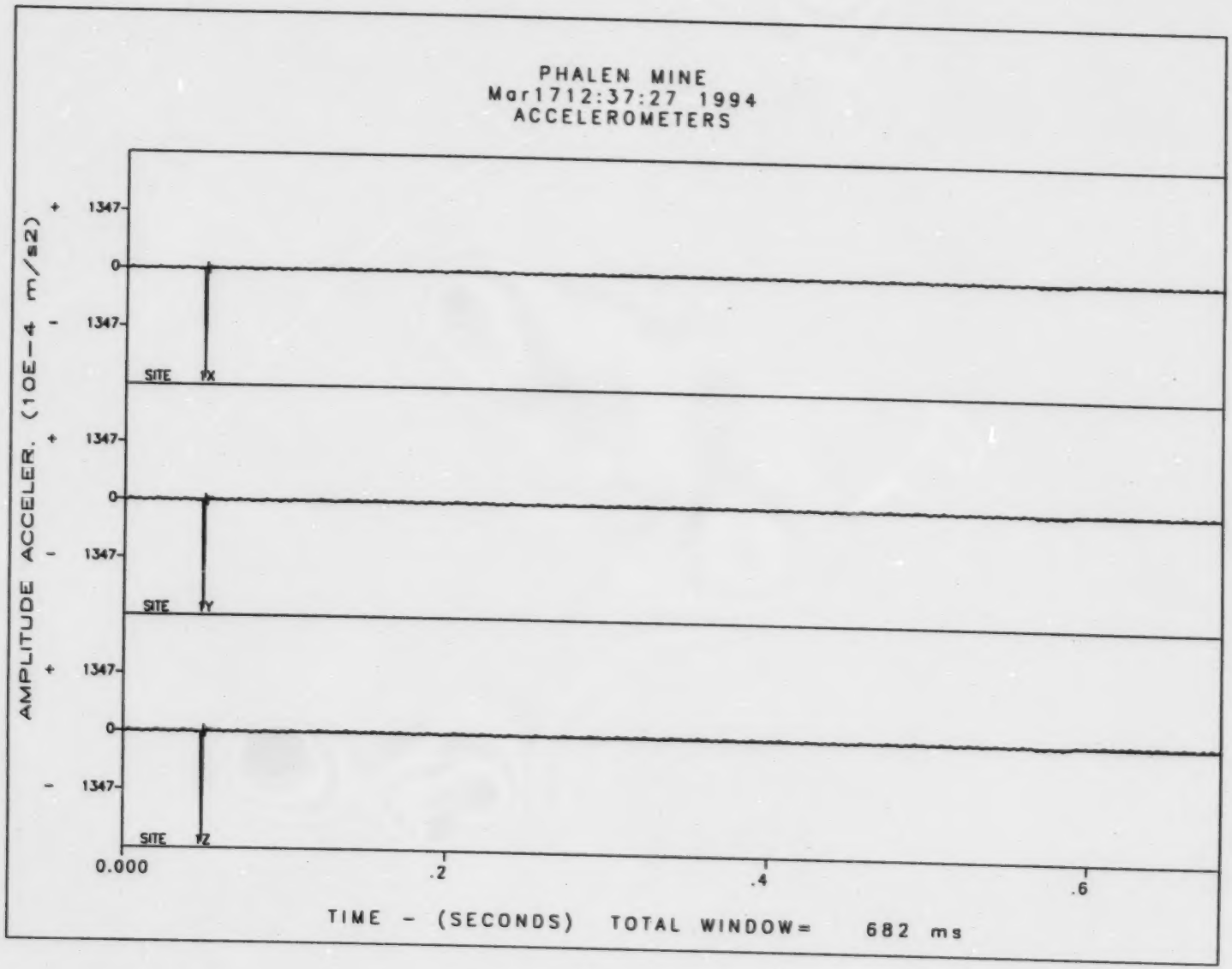

PHALEN MINE
Mar0209:22:05 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+
2055
0
-
2055
SITE 1X
+
2055
0
-
2055
SITE 1Y
+
2055
0
-
2055
SITE 1Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

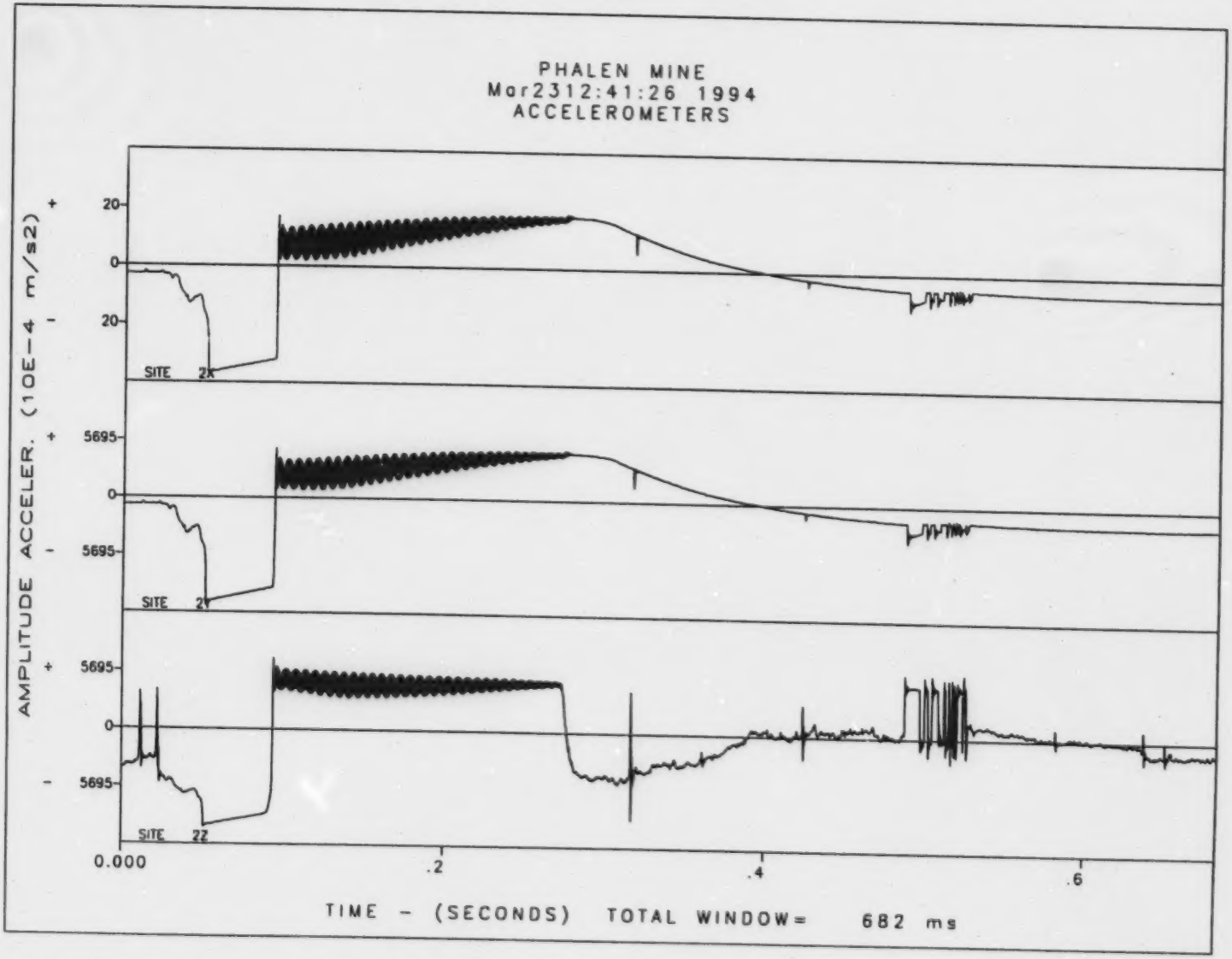

PHALEN MINE
Mar0209:22:05P 1994
SITE 1 X AXIS
-9
-10
-11
-12
-13
-14
SPECTRAL DENSITY (m-s)
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 46 TO 108 ms
FREQ=338 PLATEAU= -9.5 (log) SLOPE= -3.70

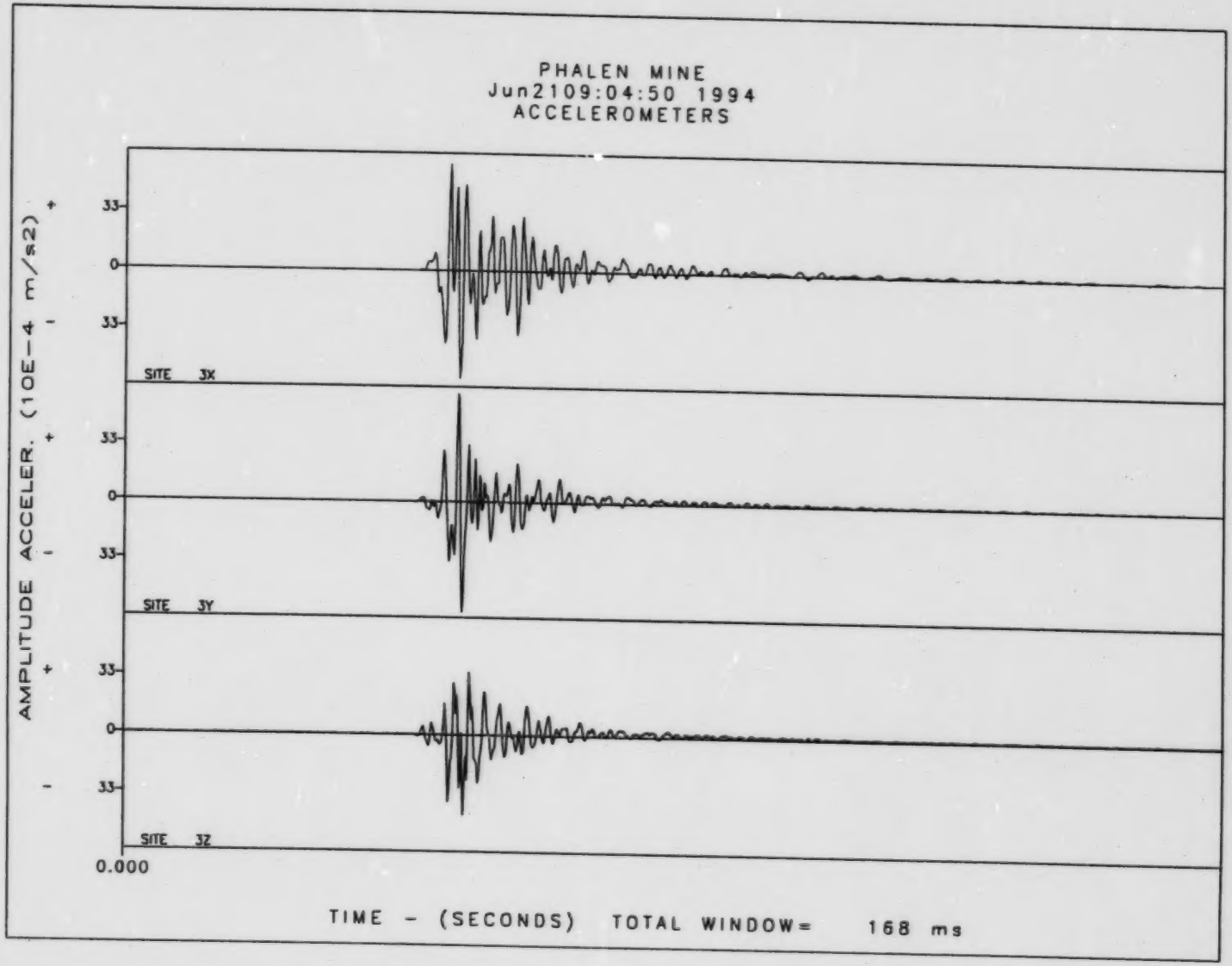

PHALEN MINE
Mar0209:22:05P 1994
SITE 1 Y AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
10
100
1000
FREQUENCY - HZ
TOTAL WIN 682 ms FFT WIN.: 46 TO 108 ms
FREQ=364 PLATEAU= -9.6 (log) SLOPE= -3.71

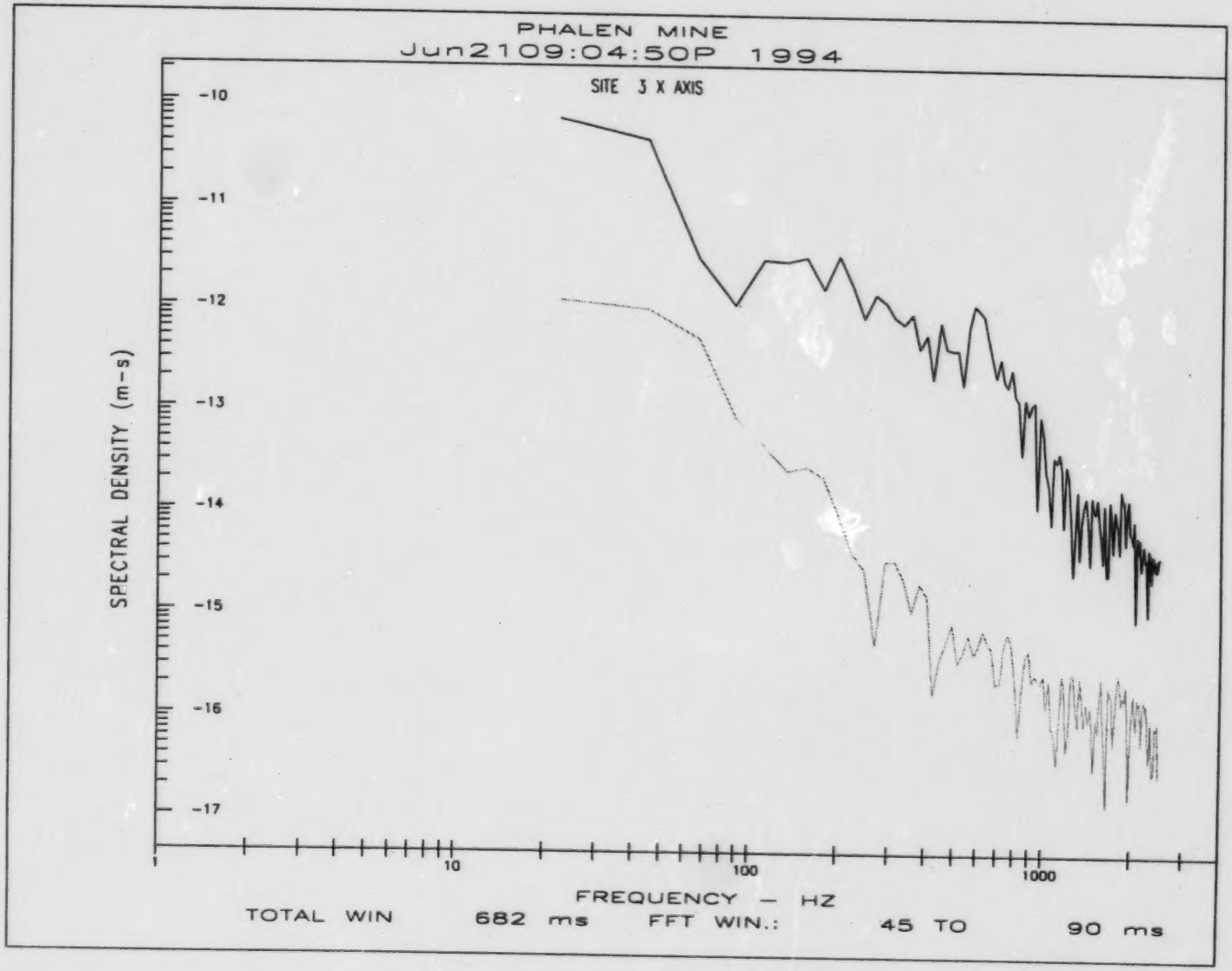

PHALEN MINE
Mar0209:22:05P 1994
SITE 1 Z AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 46 TO 108 ms
FREQ=381 PLATEAU= -9.9 (log) SLOPE= -3.73

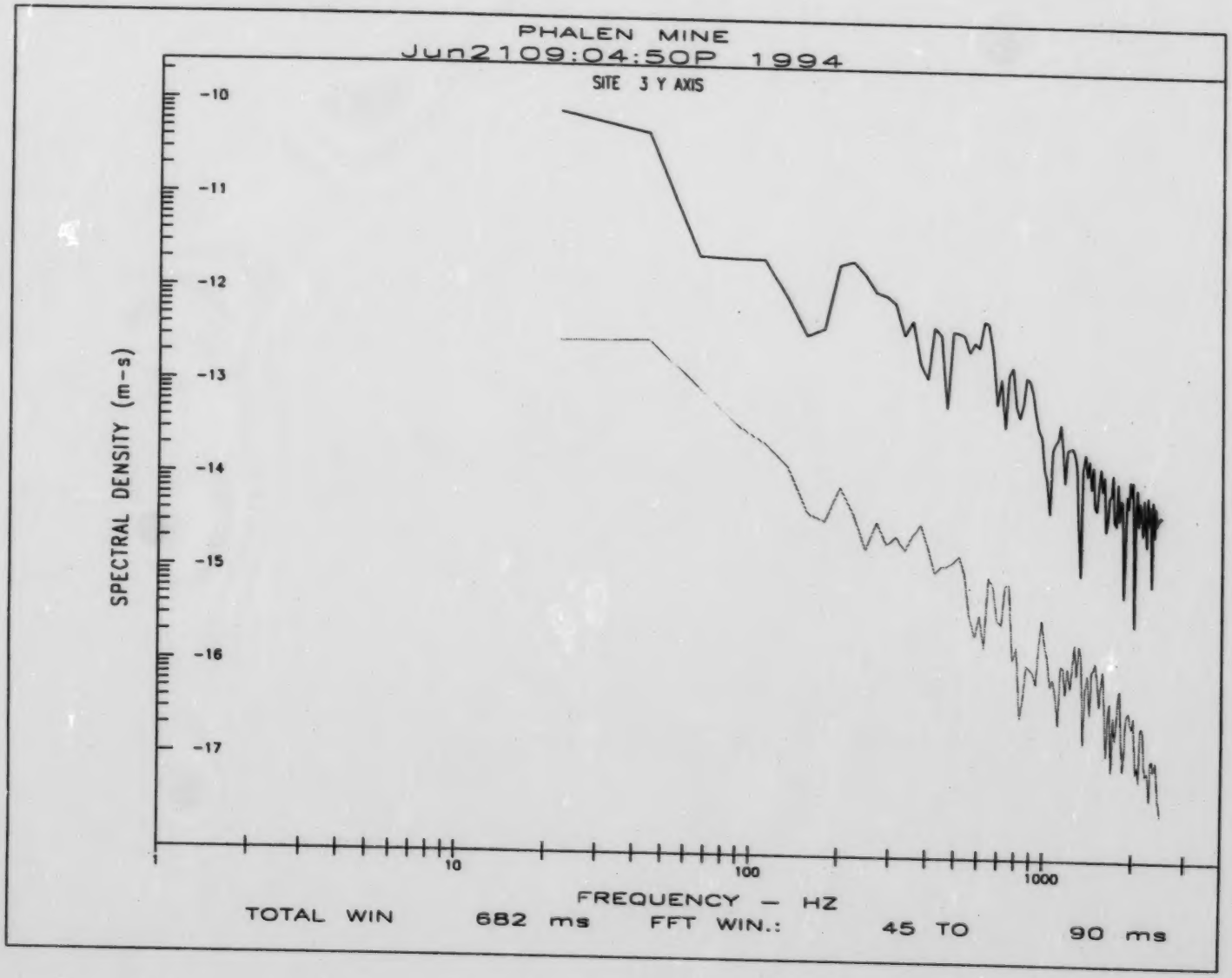

PHALEN MINE
Mar0408:47:19 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+
23
0
23
-
SITE 2X
+
23
0
23
-
SITE 2Y
+
6445
0
6445
-
SITE 2Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

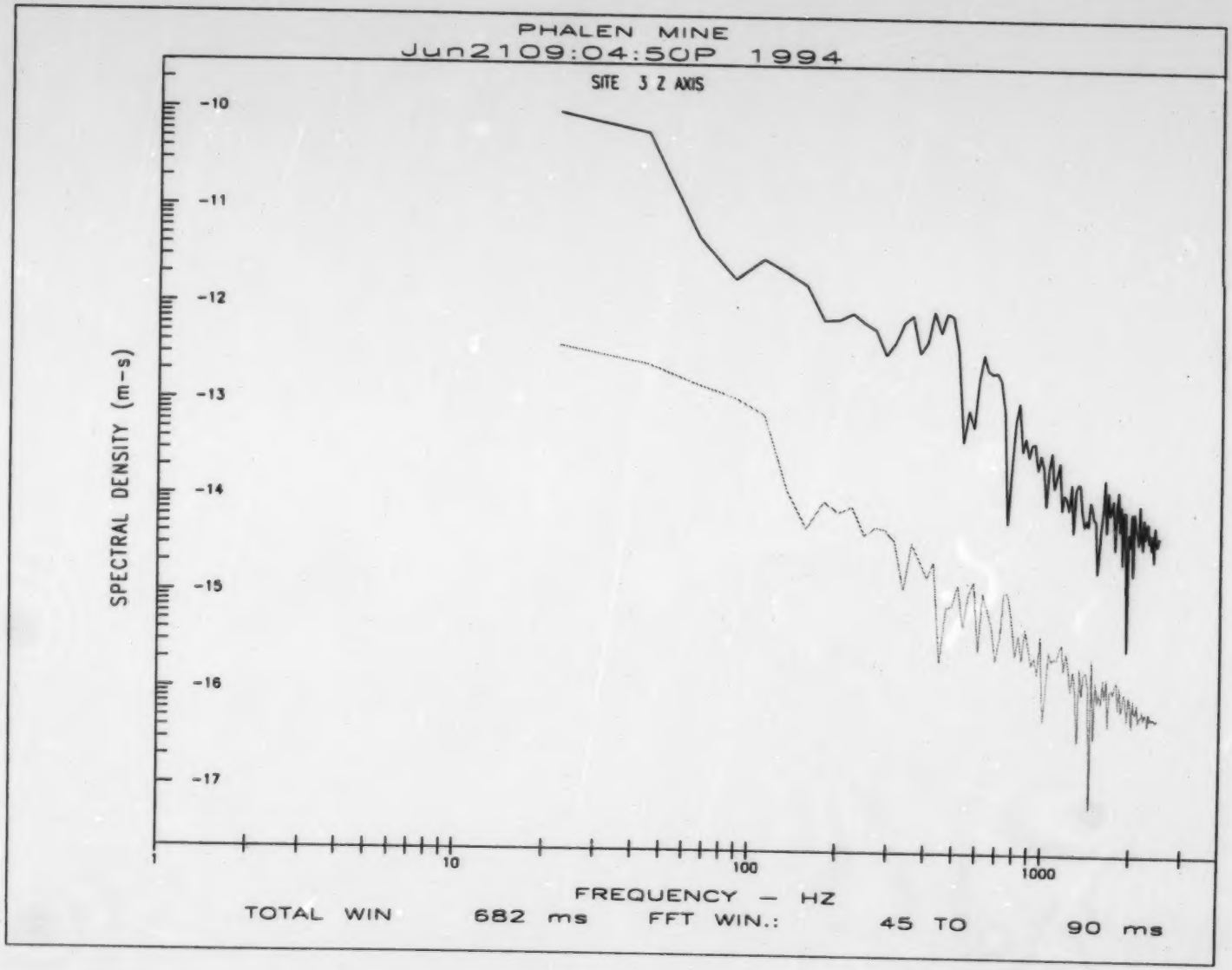

PHALEN MINE
Mar1712:37:27 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+ 1347
0
- 1347
SITE YX
+ 1347
0
- 1347
SITE YY
+ 1347
0
- 1347
SITE YZ
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

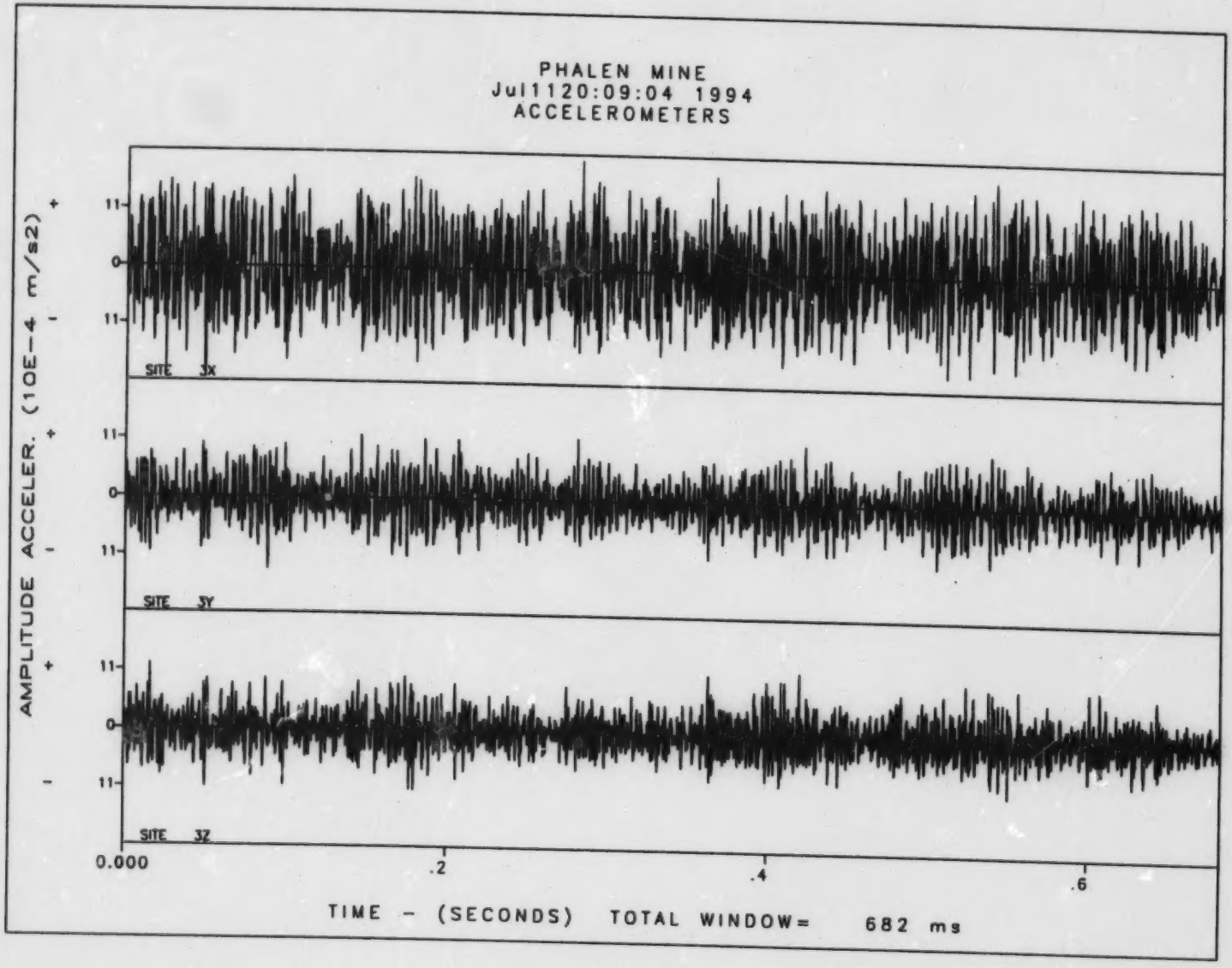

PHALEN MINE
Mar2312:41:26 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+
-
20
0
20
SITE 2X
+
5695
0
-
5695
SITE 2Y
+
5695
0
-
5695
SITE 2Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

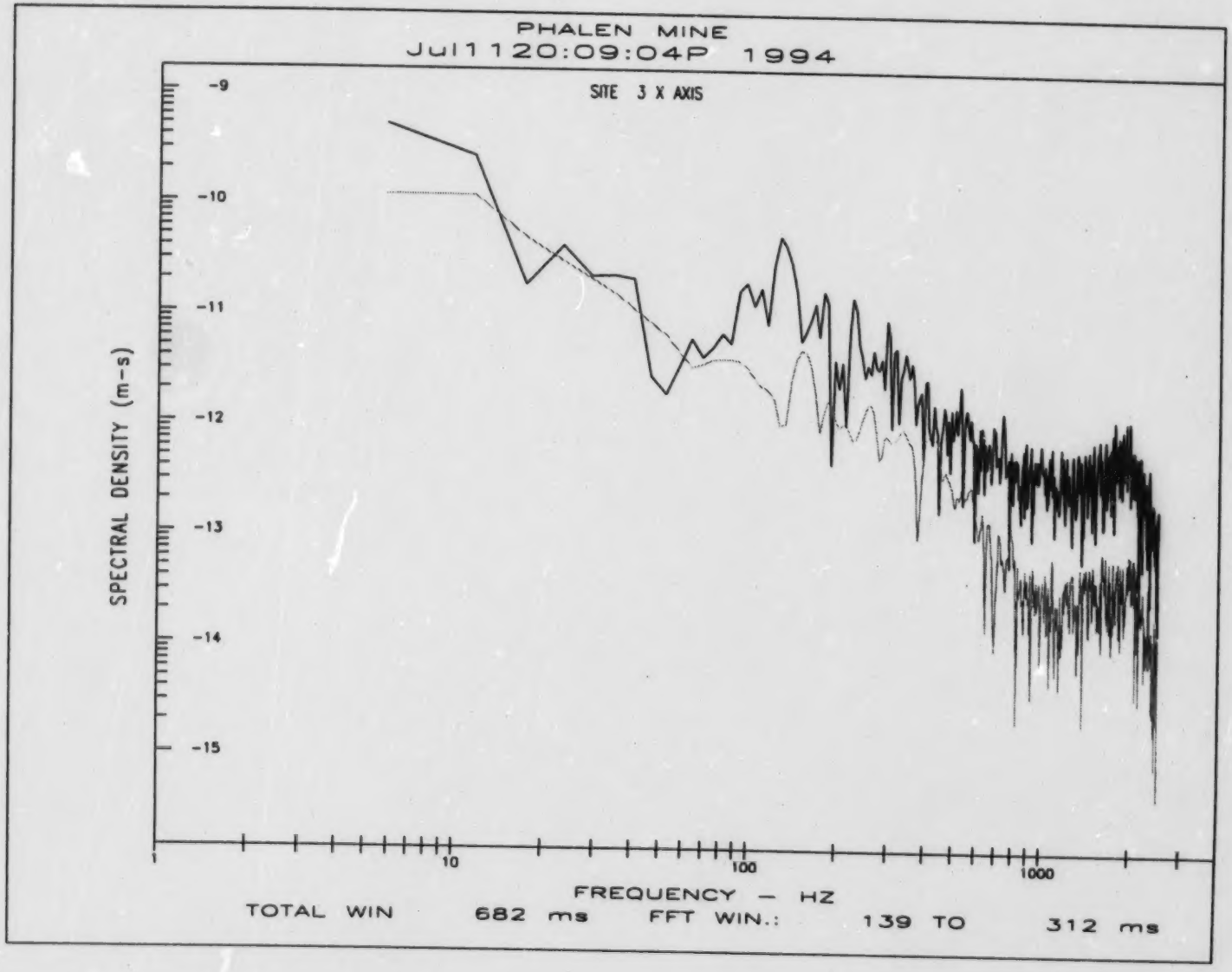

PHALEN MINE
Jun2109:04:50 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
33
0
33
SITE 3X
SITE 3Y
SITE 3Z
0.000
TIME - (SECONDS) TOTAL WINDOW= 168 ms

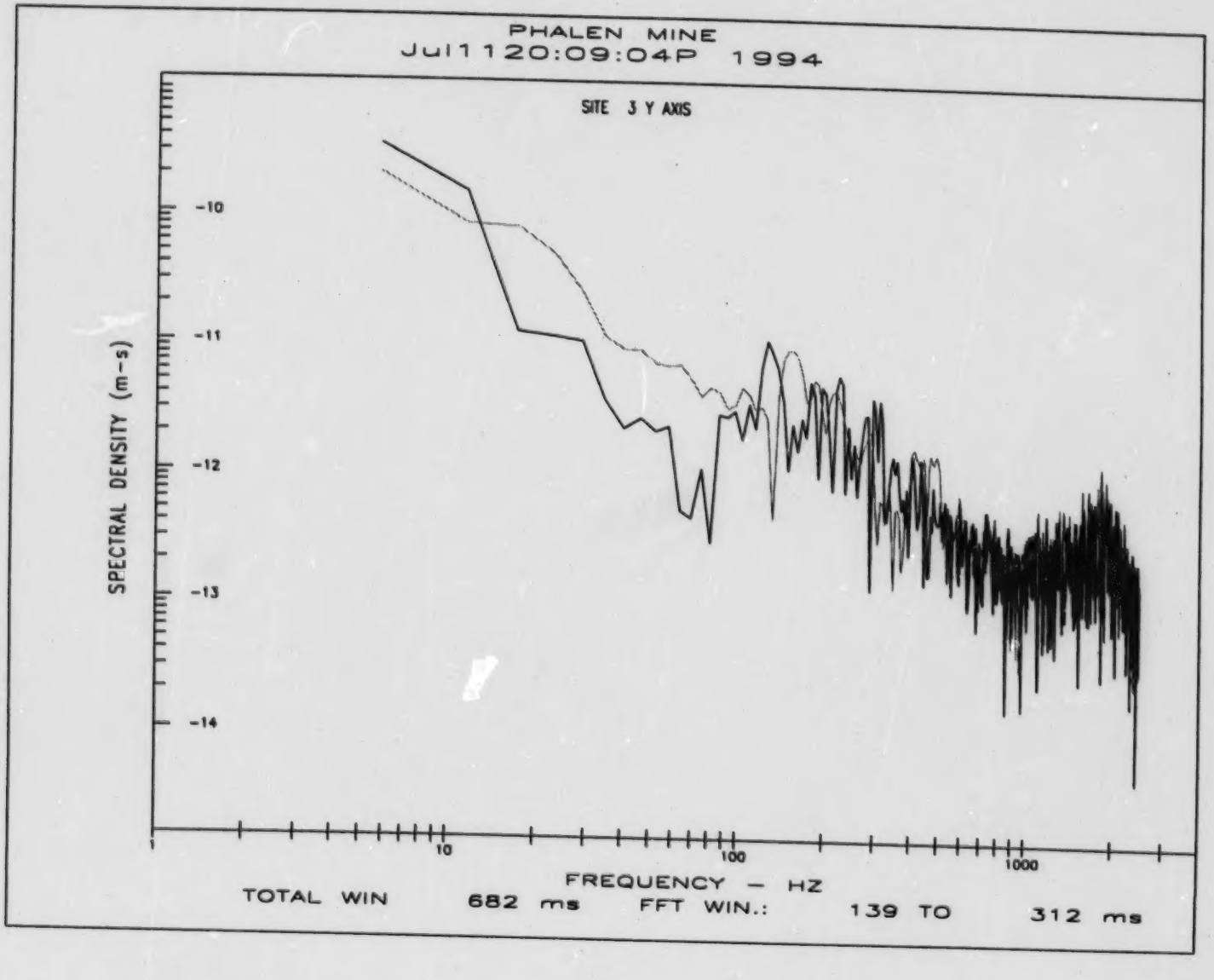

PHALEN MINE
Jun2109:04:50P 1994
SITE 3 X AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
-15
-16
-17
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 45 TO 90 ms

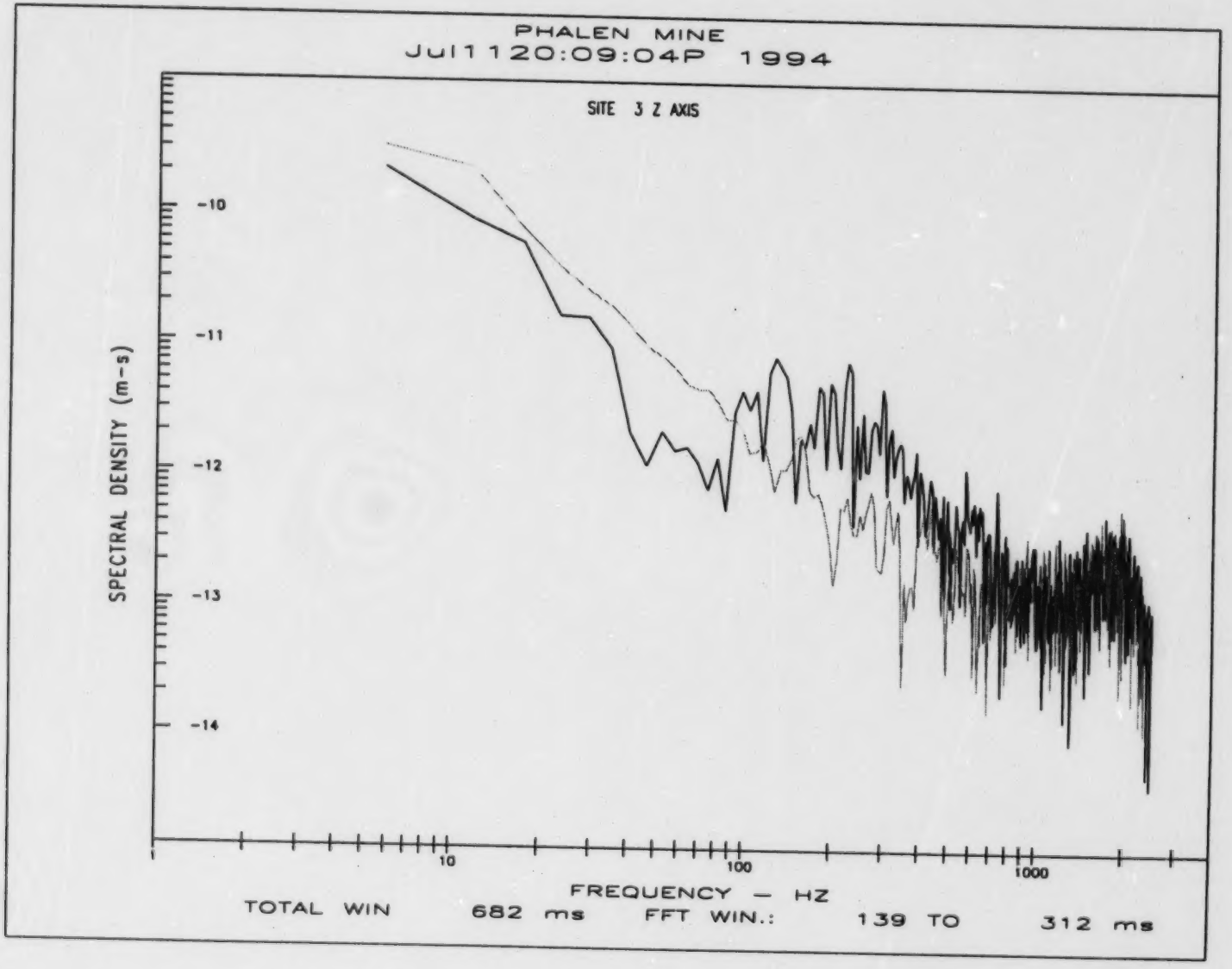

PHALEN MINE
Jun2109:04:50P 1994
SITE 3 Y AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
-15
-16
-17
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 45 TO 90 ms

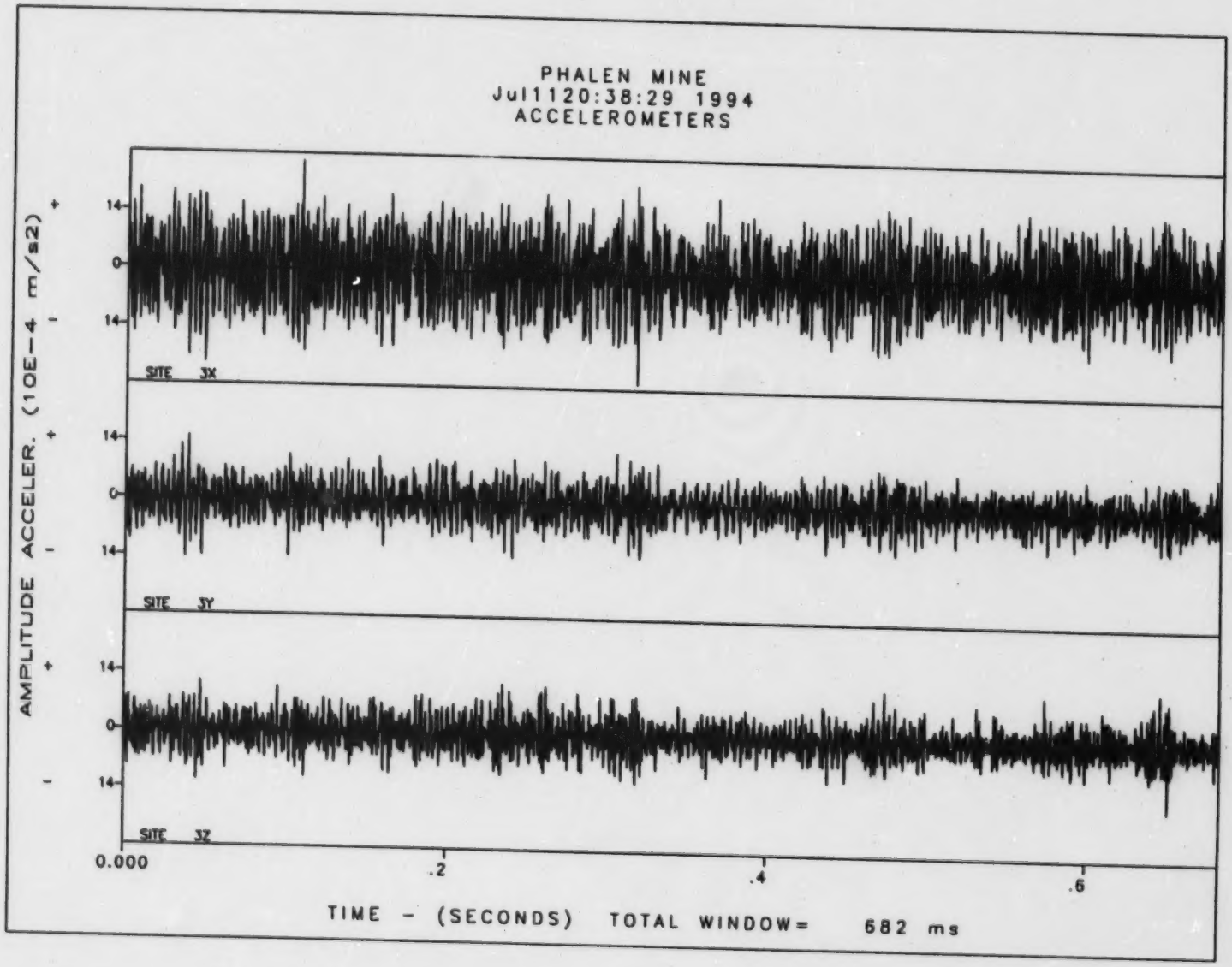

PHALEN MINE
Jun2109:04:50P 1994
SITE 3 Z AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
-15
-16
-17
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 45 TO 90 ms

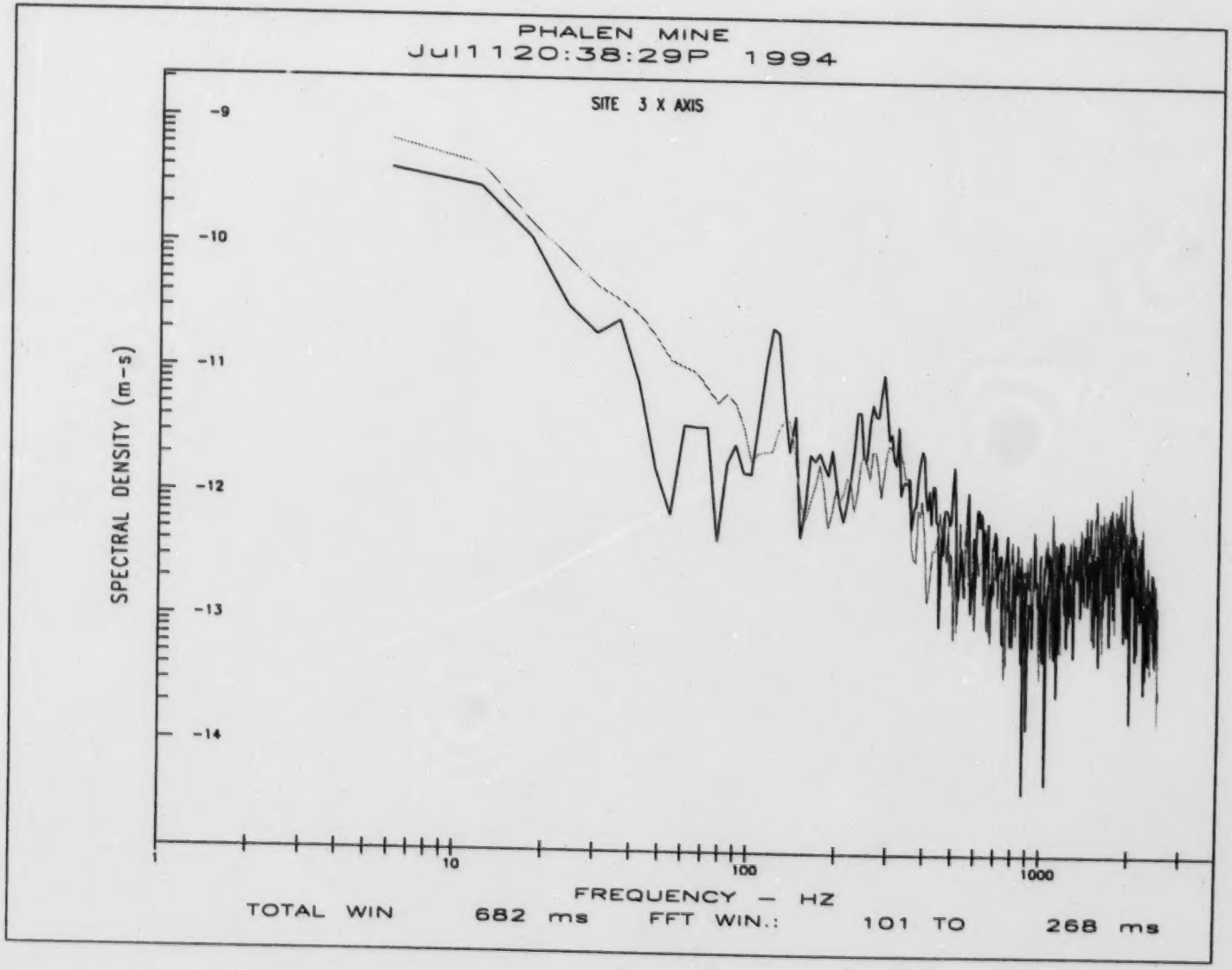

PHALEN MINE
Jul1120:09:04 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+
-
11
0
11
SITE 3X
SITE 3Y
SITE 3Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

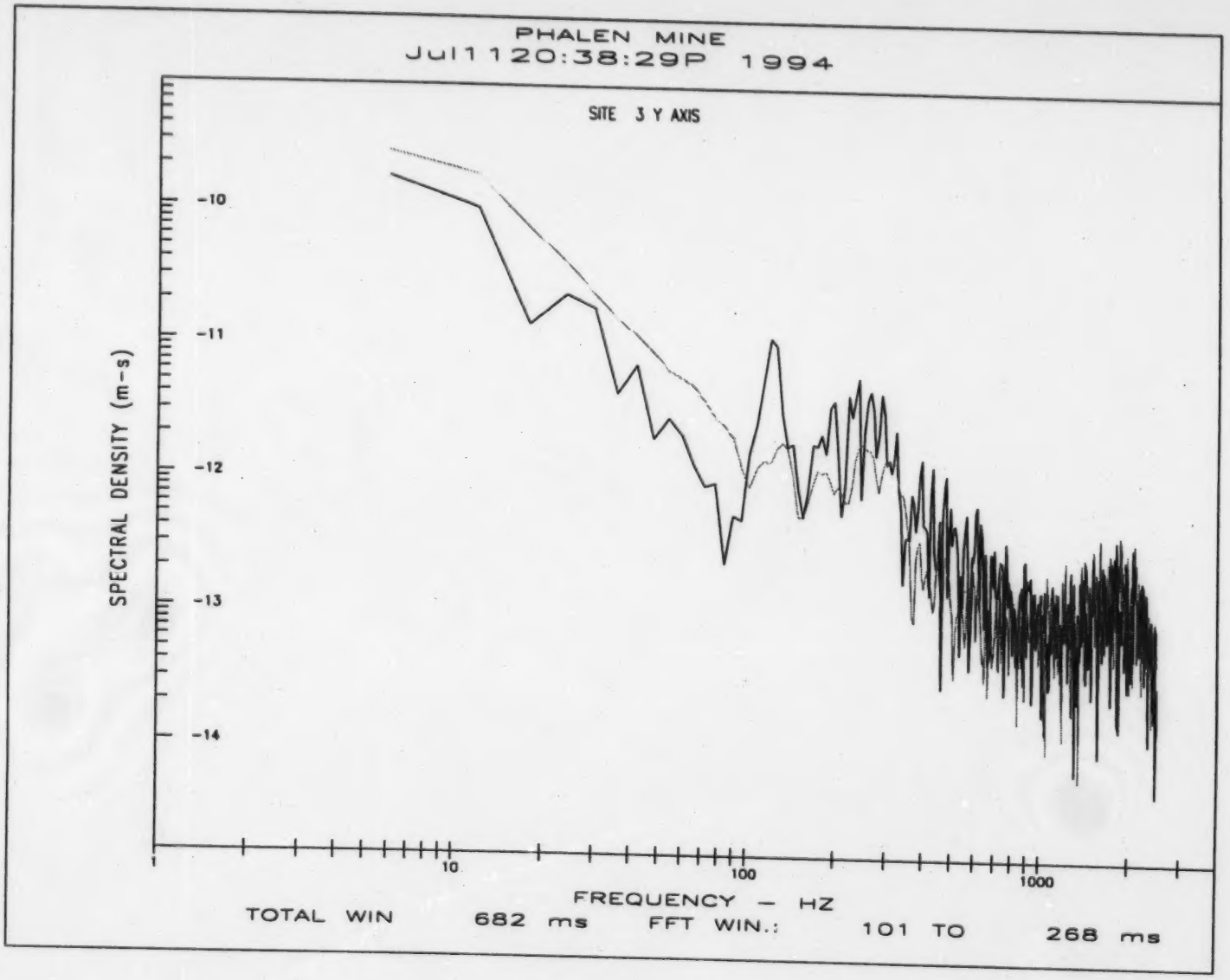

PHALEN MINE
Jul1120:09:04P 1994
SITE 3 X AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
10
100
1000
FREQUENCY - HZ
TOTAL WIN 682 ms FFT WIN.: 139 TO 312 ms

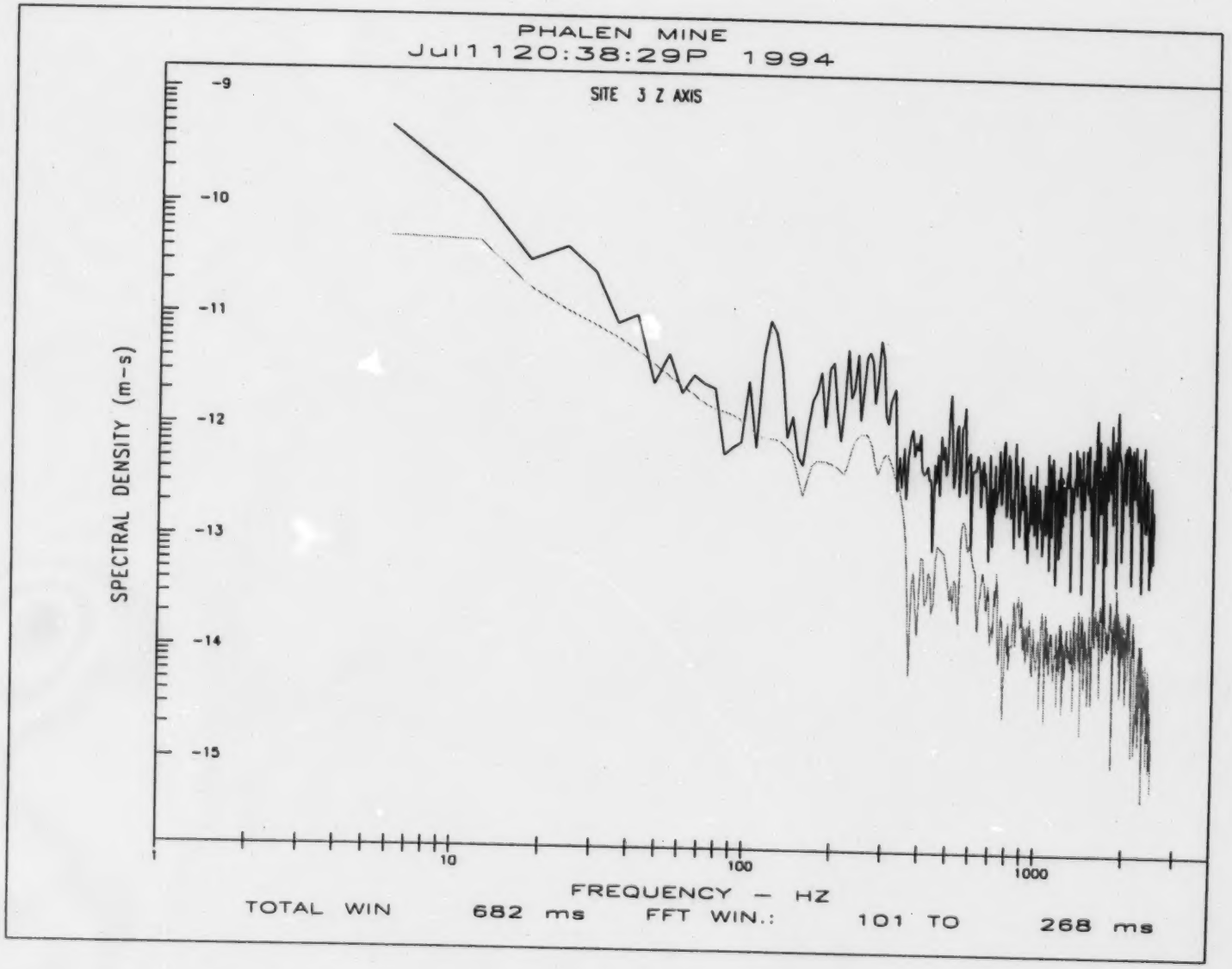

PHALEN MINE
Jul1120:09:04P 1994
SITE 3 Y AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
1
10
100
1000
FREQUENCY - HZ
TOTAL WIN 682 ms FFT WIN.: 139 TO 312 ms

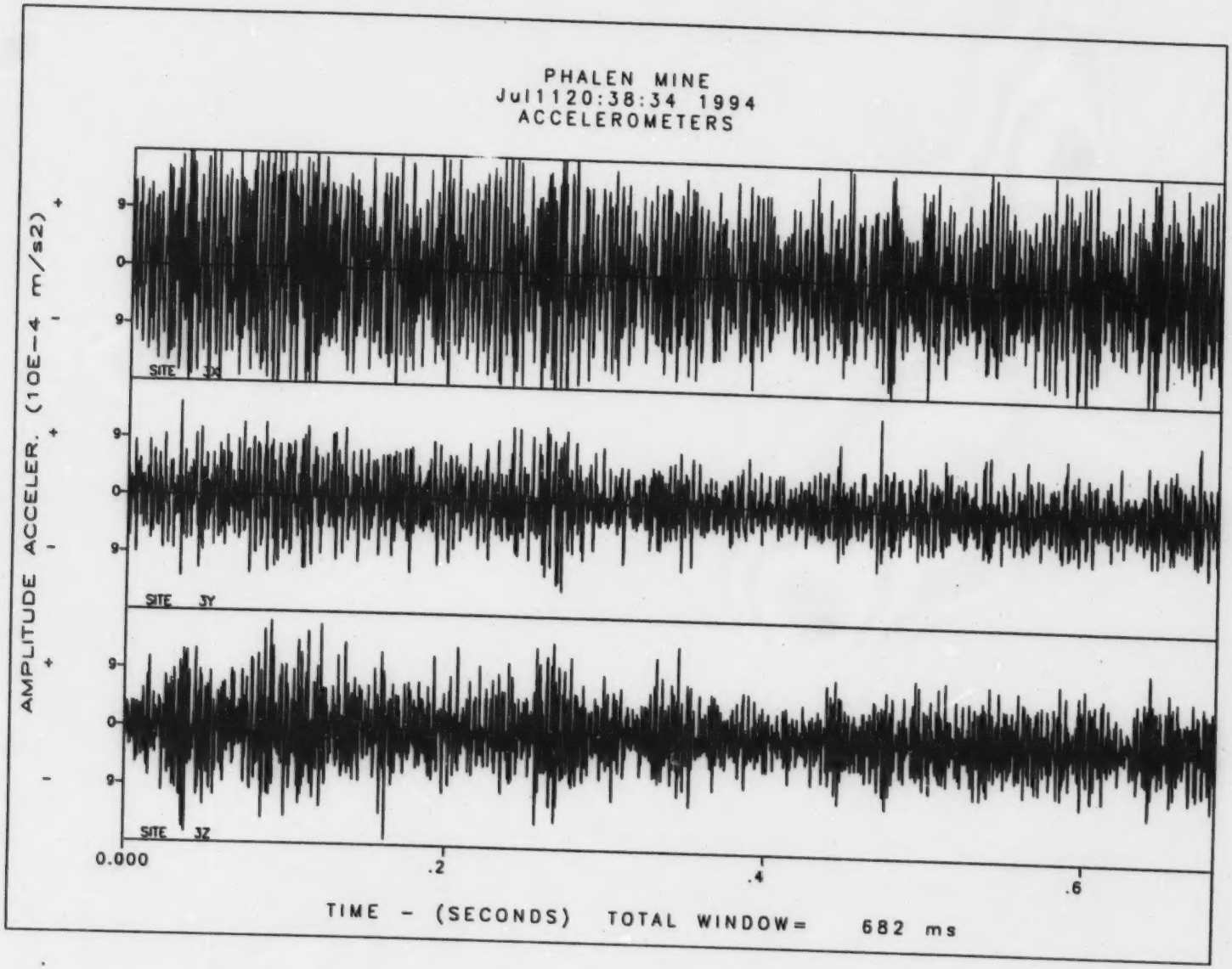

PHALEN MINE
Jul1120:09:04P 1994
SITE 3 Z AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 139 TO 312 ms

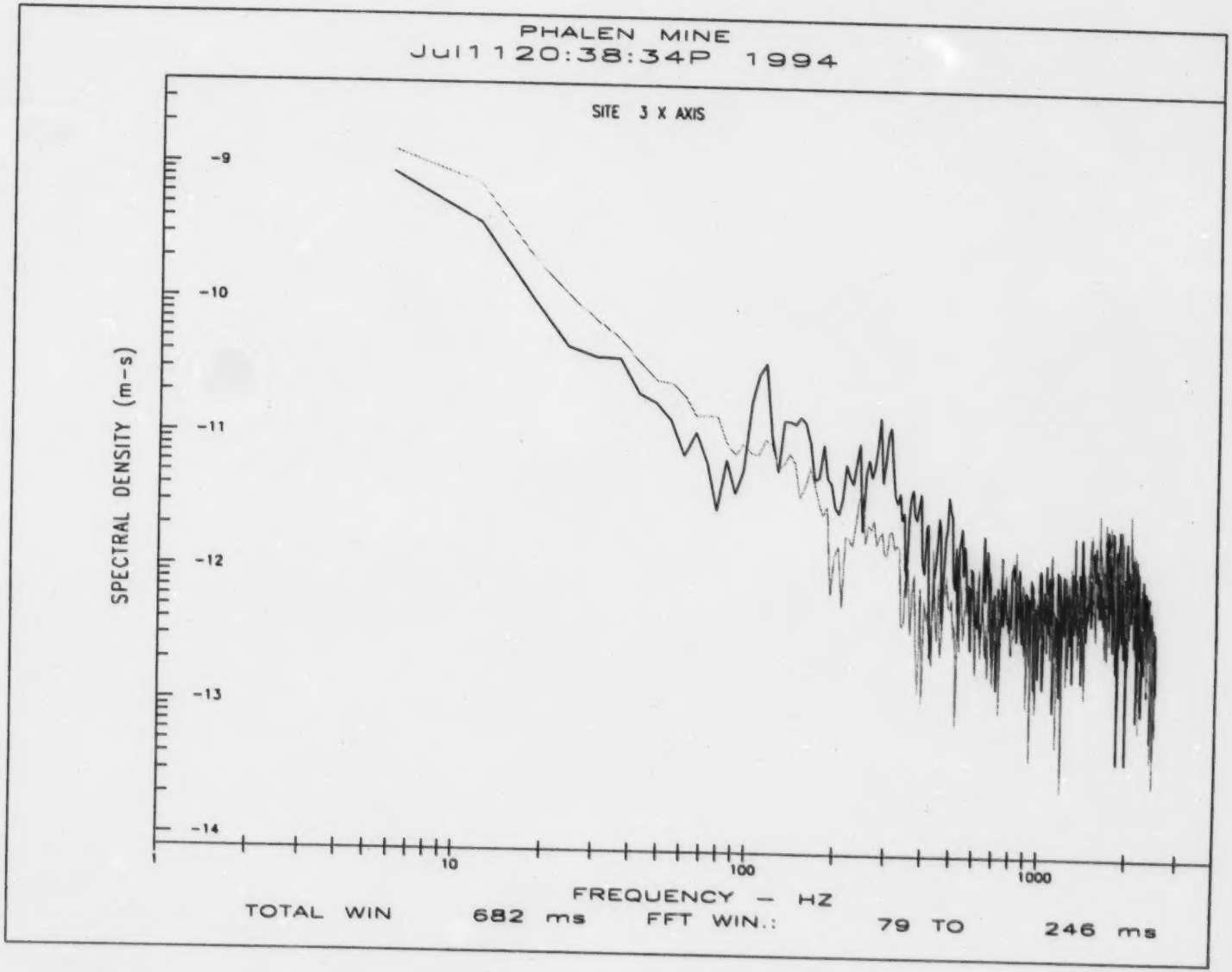

PHALEN MINE
Jul1120:38:29 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+
-
14
0
14
SITE 3X
SITE 3Y
SITE 3Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

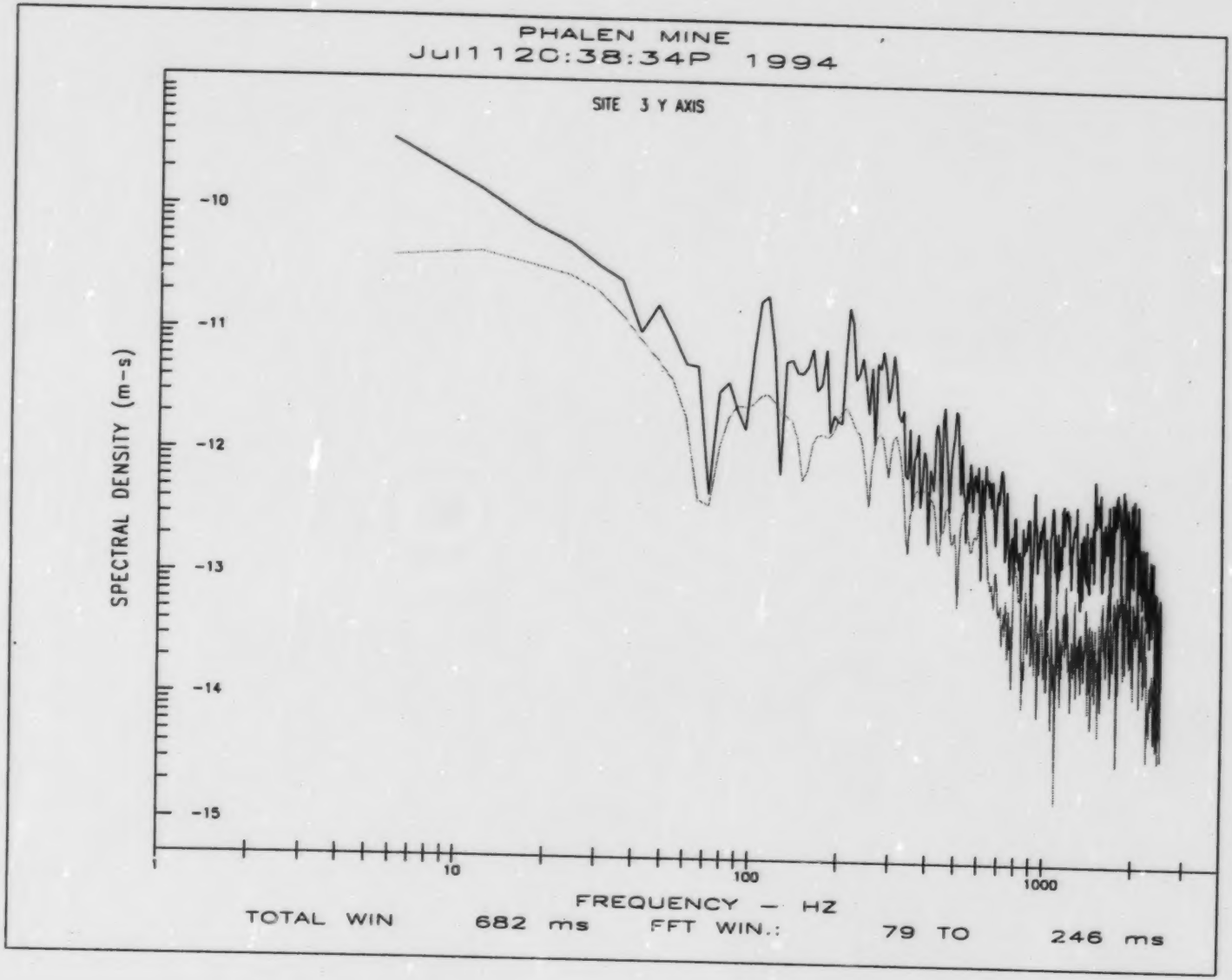

PHALEN MINE
Jul1120:38:29P 1994
SITE 3 X AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
10
100
1000
FREQUENCY - HZ
TOTAL WIN 682 ms FFT WIN.: 101 TO 268 ms

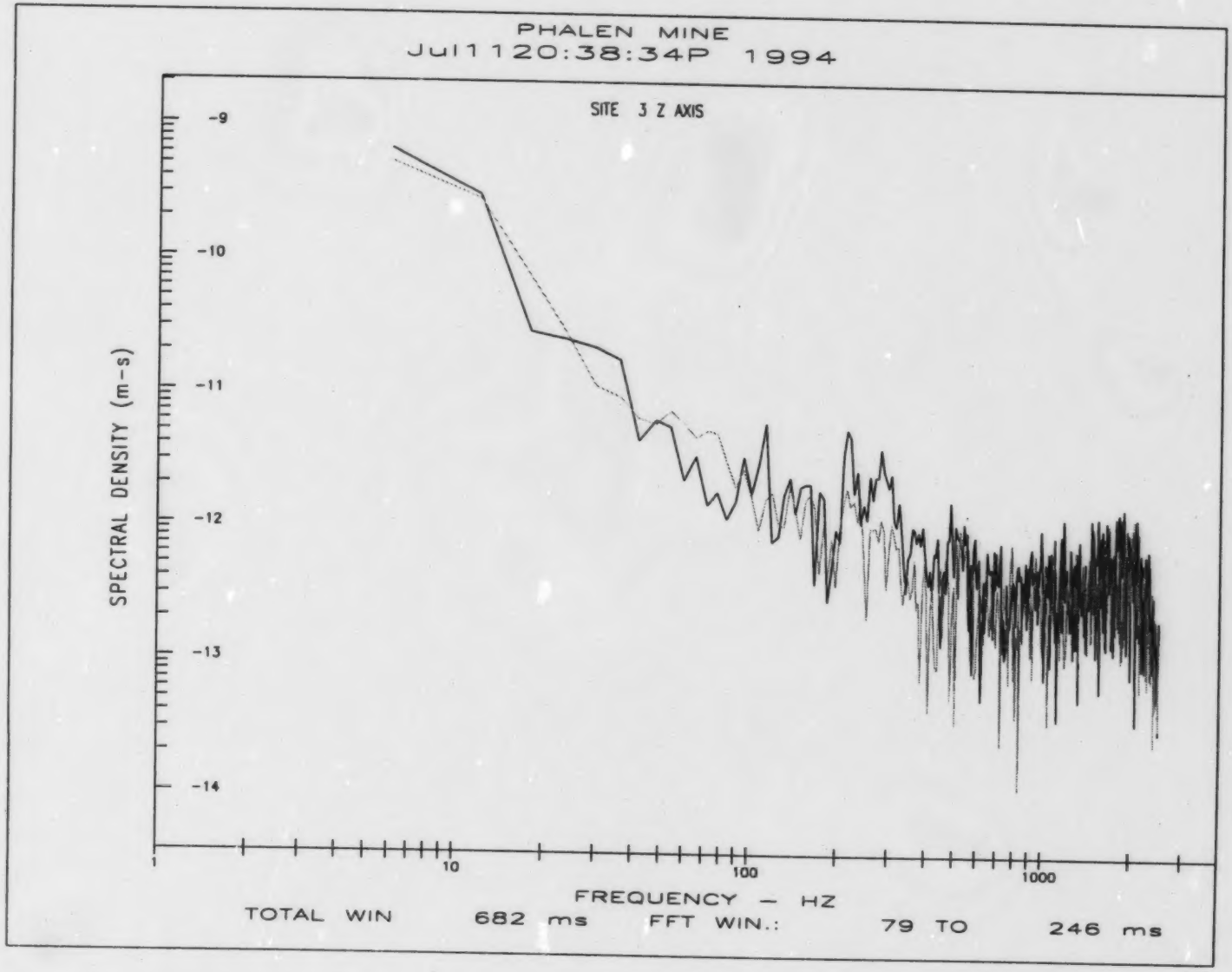

PHALEN MINE
Jul1120:38:29P 1994
SITE 3 Y AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 101 TO 268 ms

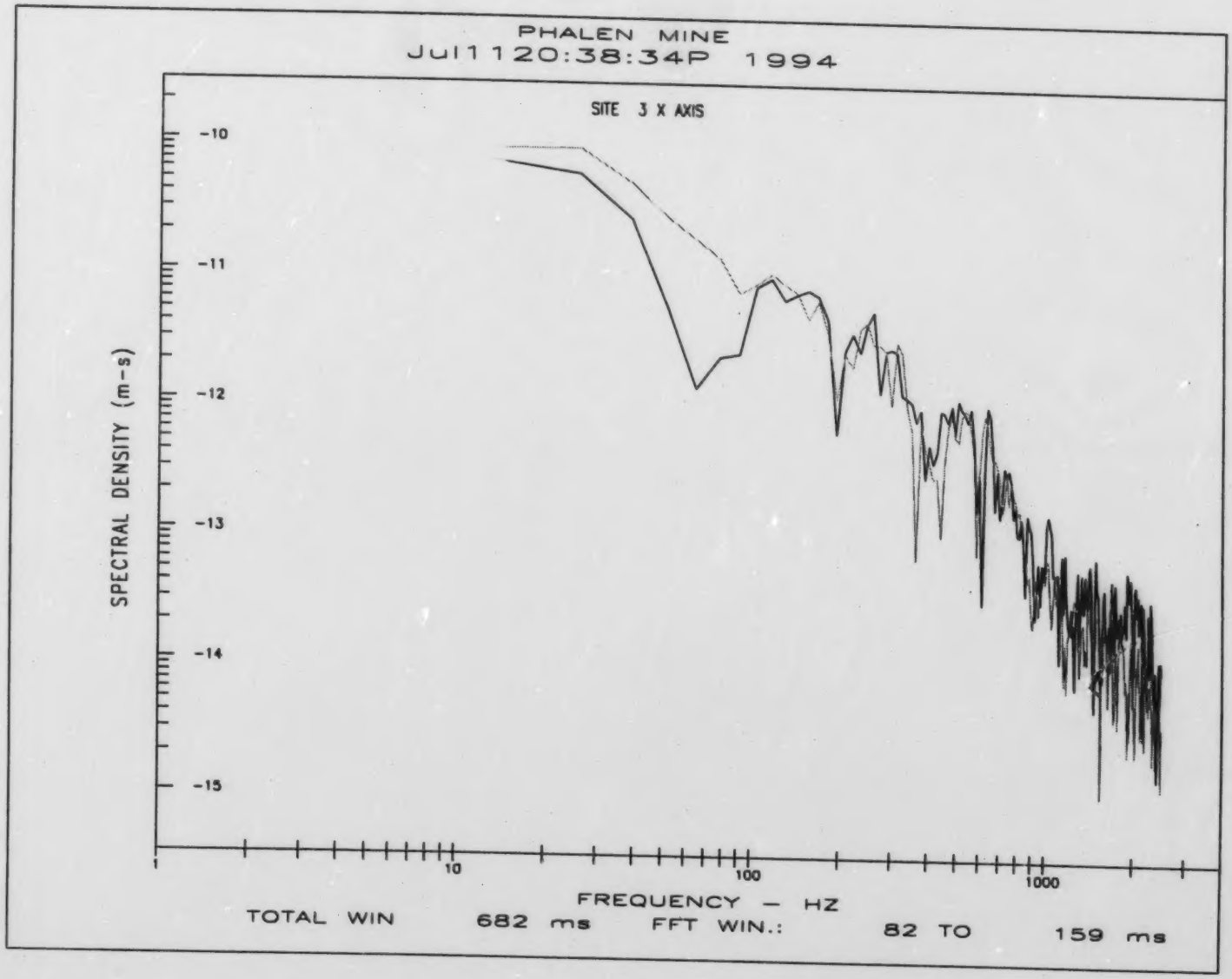

PHALEN MINE
Jul1120:38:29P 1994
SITE 3 Z AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 101 TO 268 ms

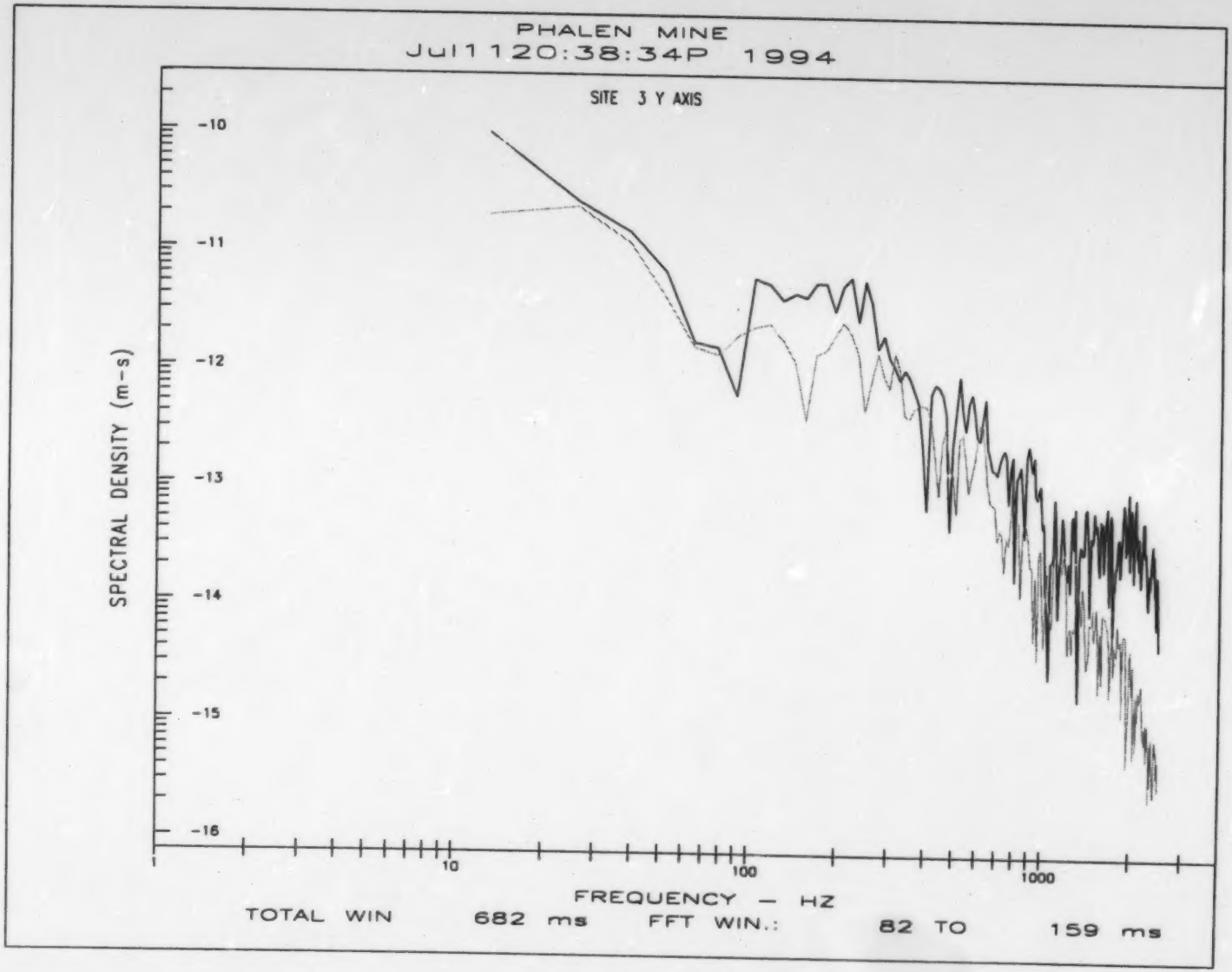

PHALEN MINE
Jul1120:38:34 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
SITE 3X
SITE 3Y
SITE 3Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

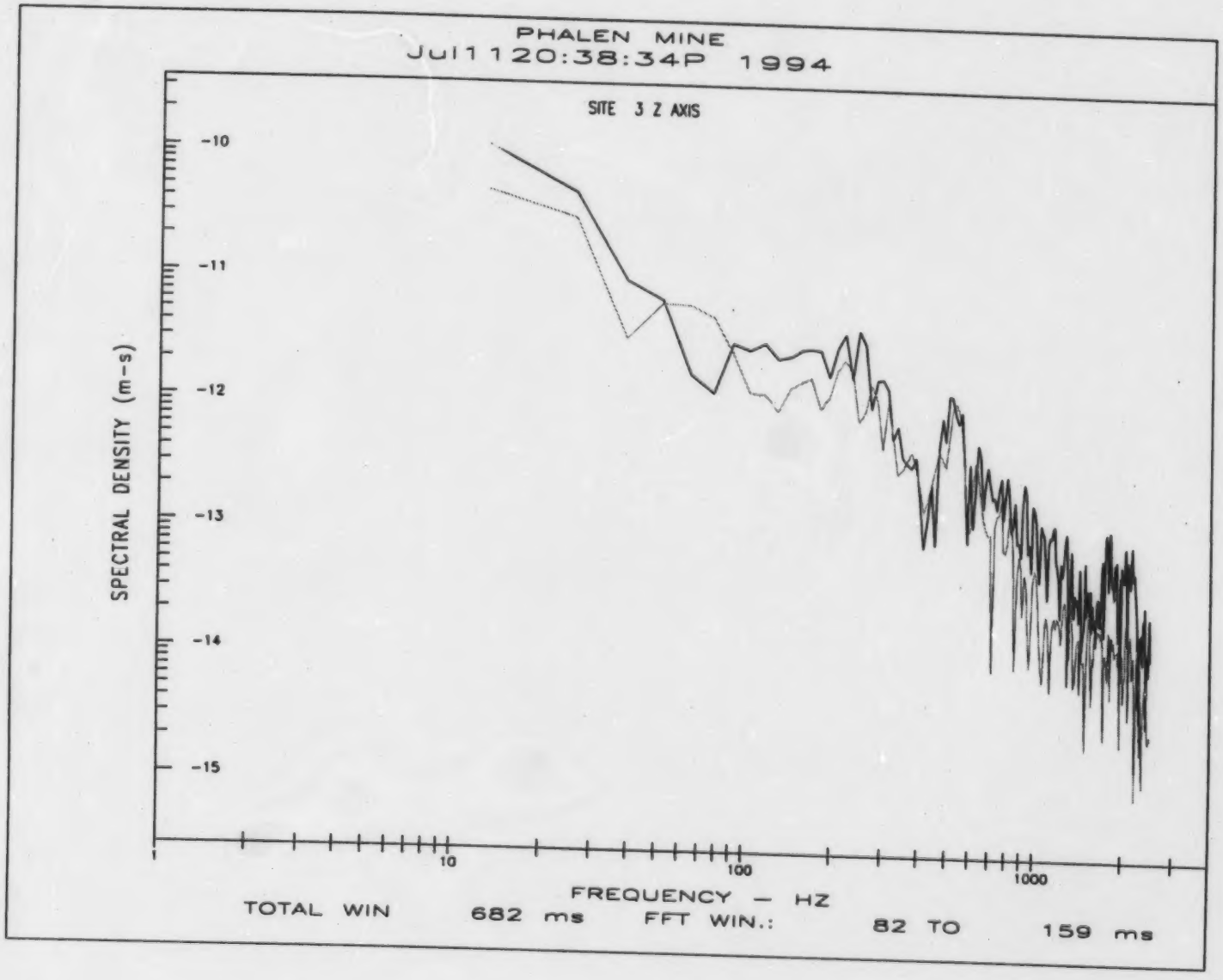

PHALEN MINE
Jul1120:38:34P 1994
SITE 3 X AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
10
100
1000
FREQUENCY - HZ
TOTAL WIN 682 ms FFT WIN.: 79 TO 246 ms

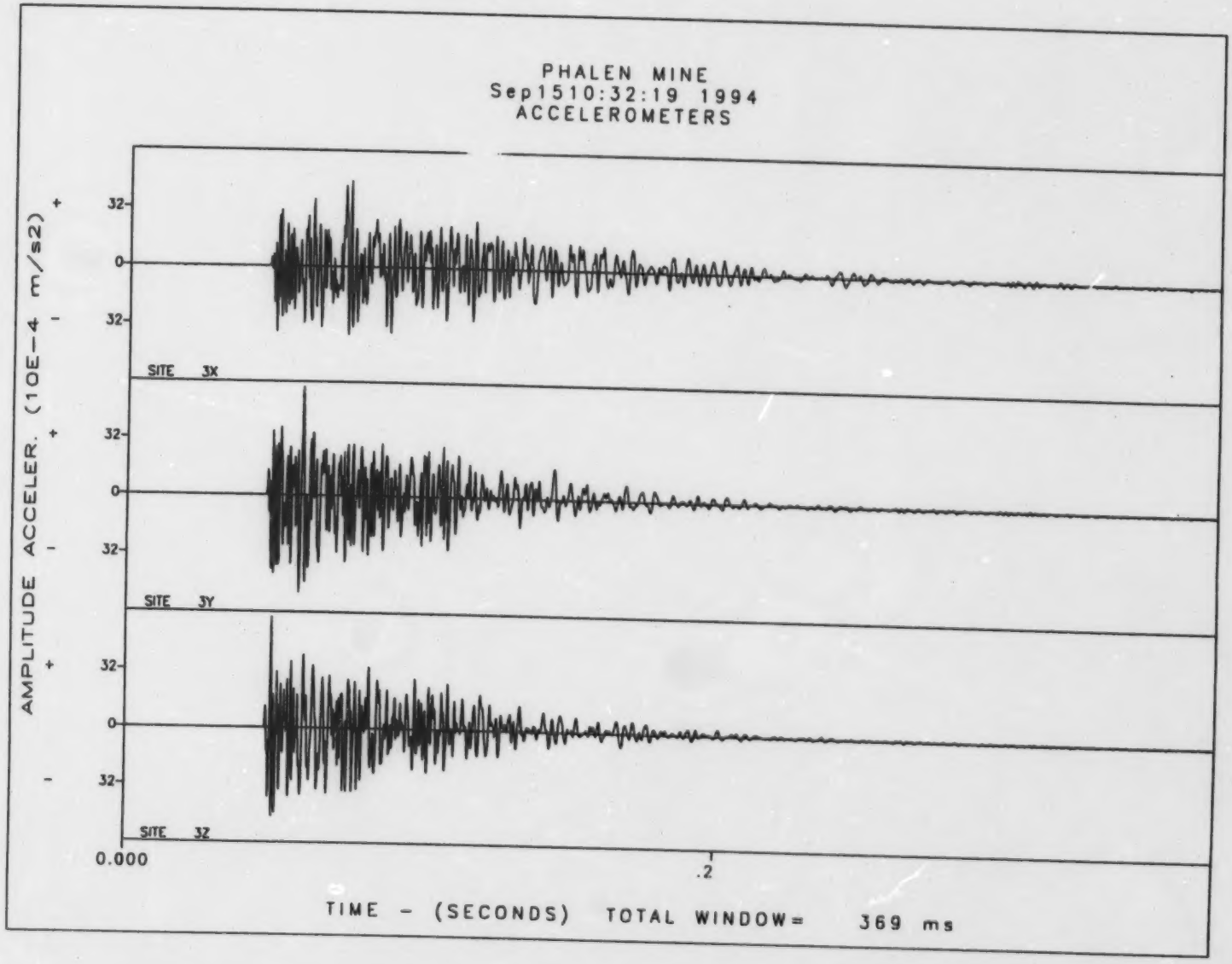

PHALEN MINE
Jul1120:38:34P 1994
SITE 3 Y AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
-15
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 79 TO 246 ms

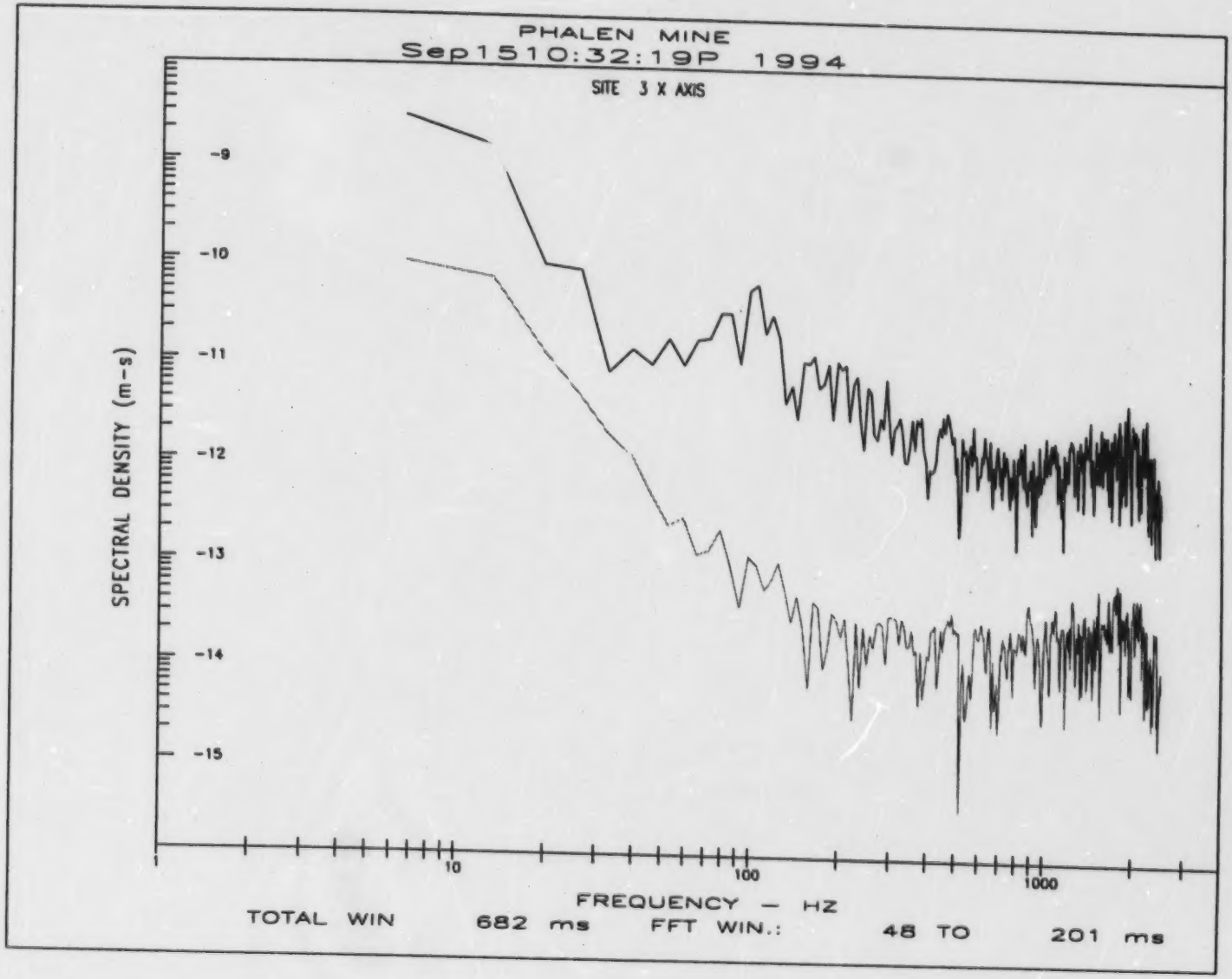

PHALEN MINE
Jul1120:38:34P 1994
SITE 3 Z AXIS
-9
-10
-11
-12
-13
-14
SPECTRAL DENSITY (m-s)
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 79 TO 246 ms

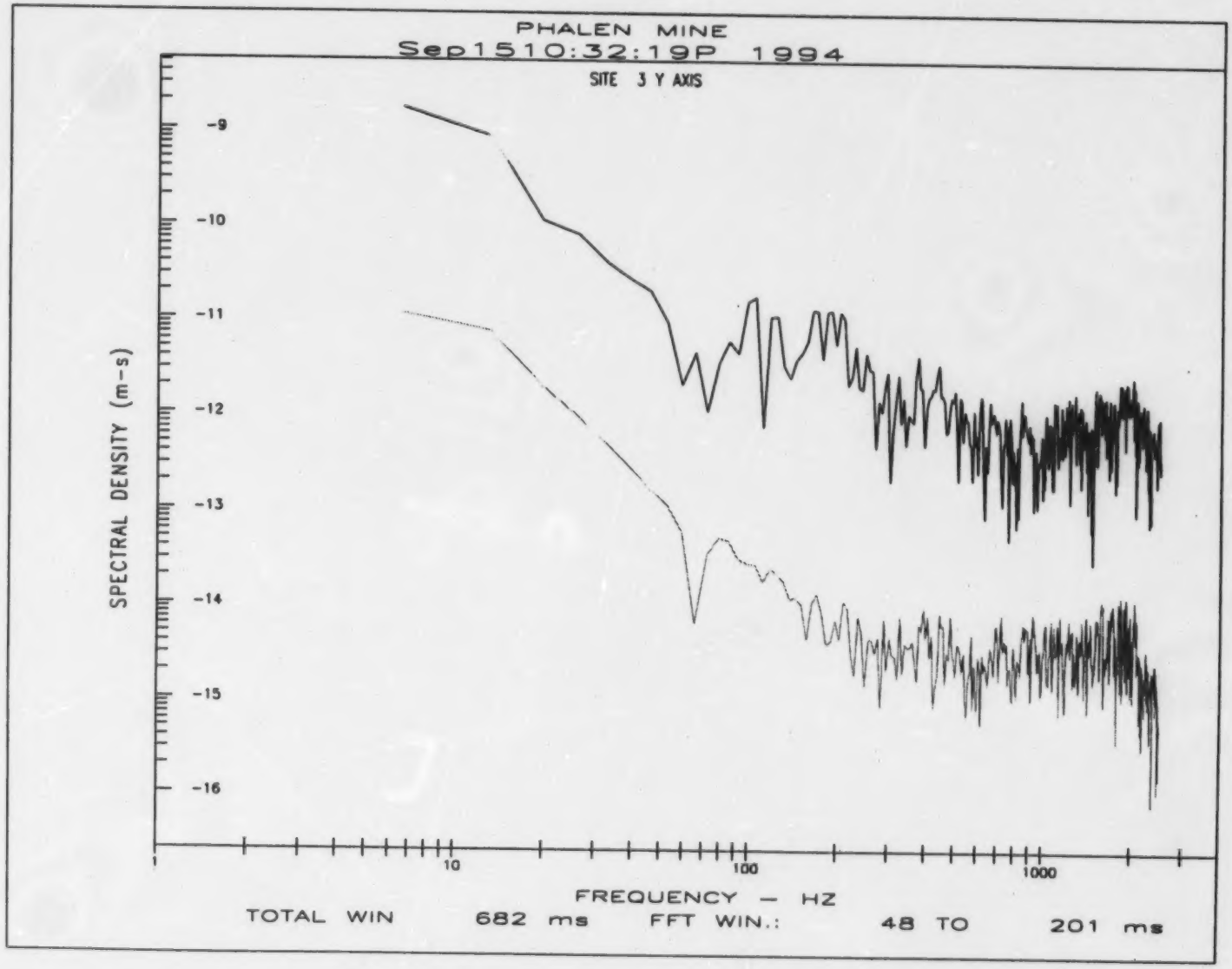

PHALEN MINE
Jul1120:38:34P 1994
SITE 3 X AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
-15
1
10
100
1000
FREQUENCY - HZ
TOTAL WIN 682 ms FFT WIN.: 82 TO 159 ms

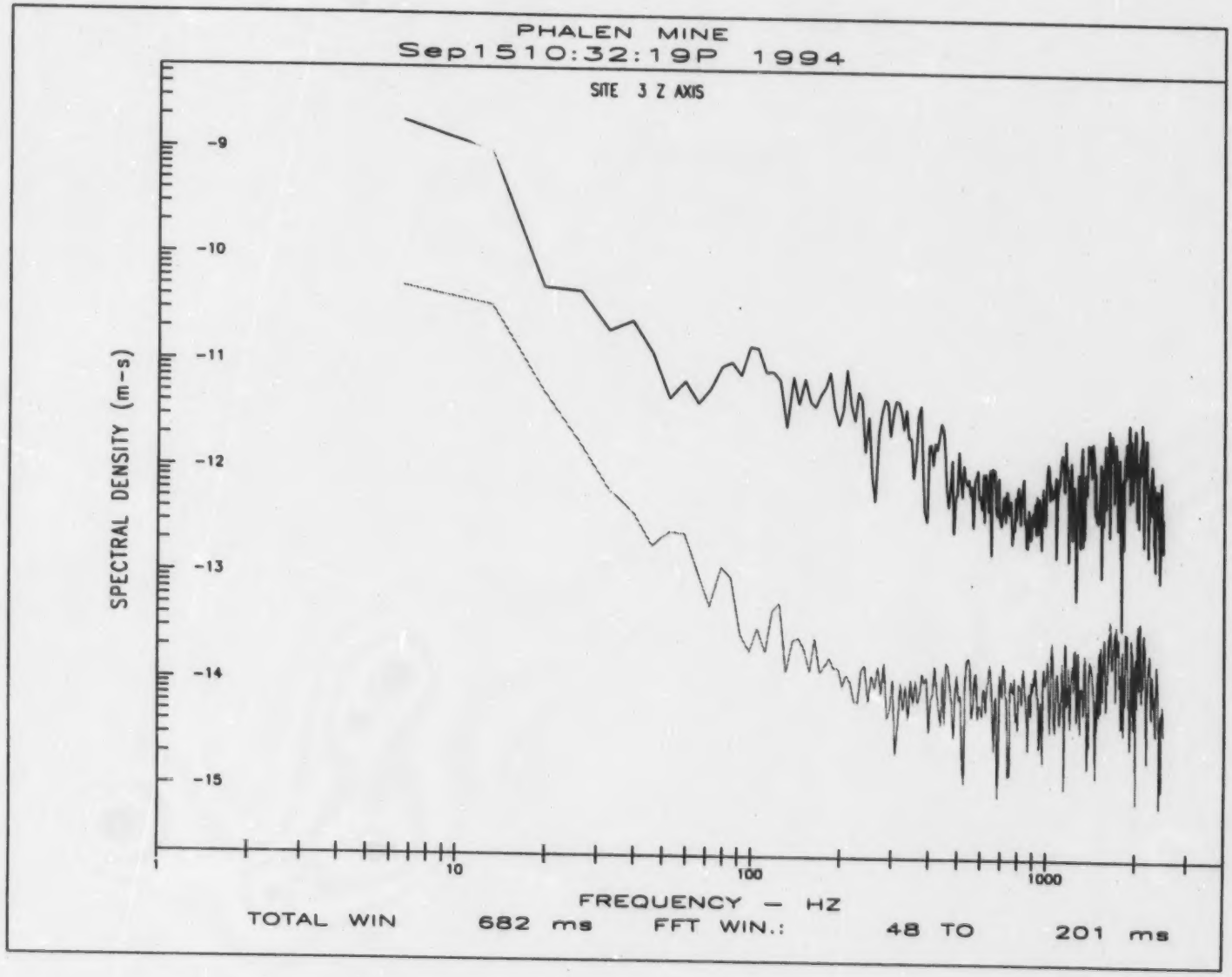

PHALEN MINE
Jul1120:38:34P 1994
SITE 3 Y AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
-15
-16
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 82 TO 159 ms

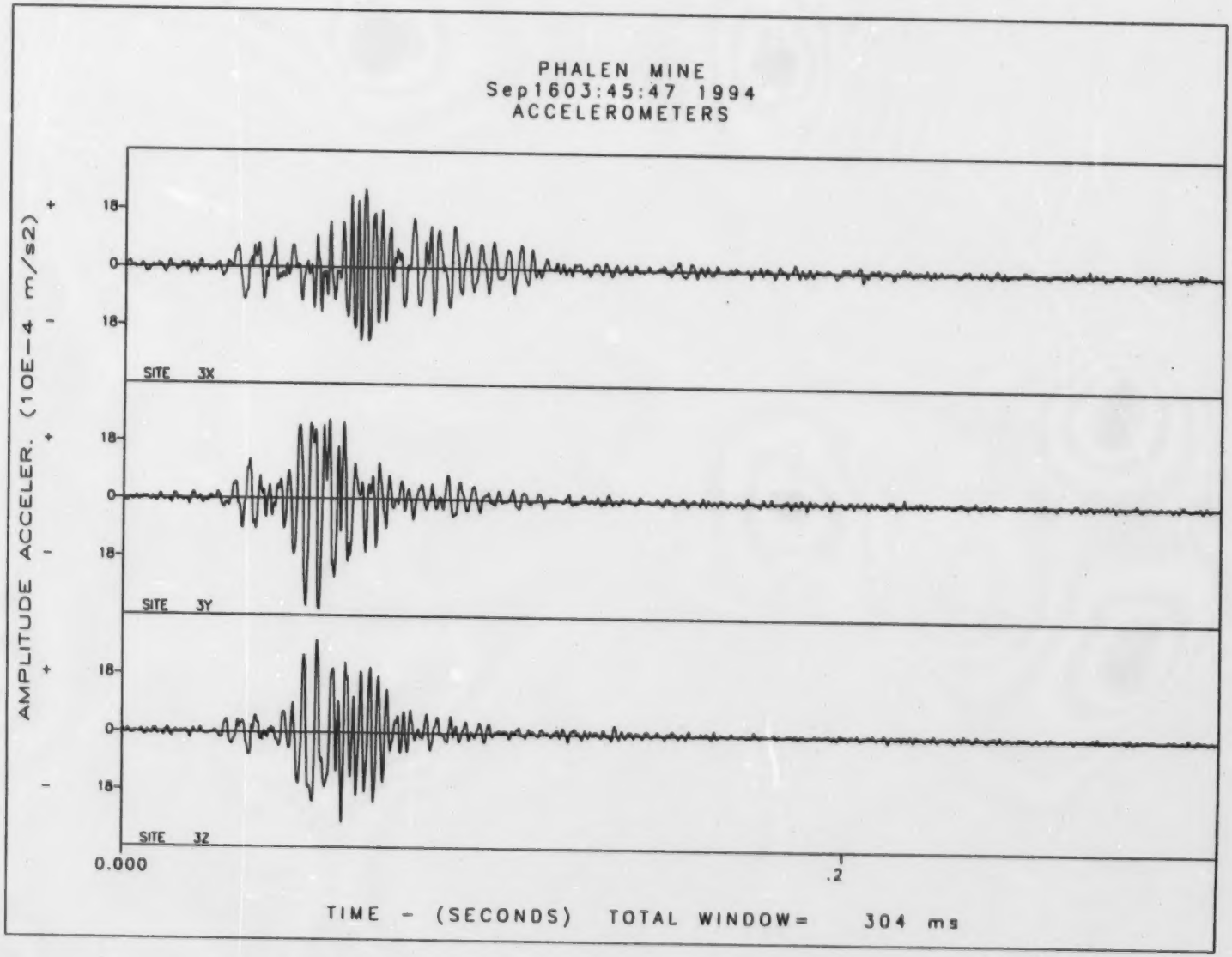

PHALEN MINE
Jul1120:38:34P 1994
SITE 3 Z AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
-15
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 82 TO 159 ms

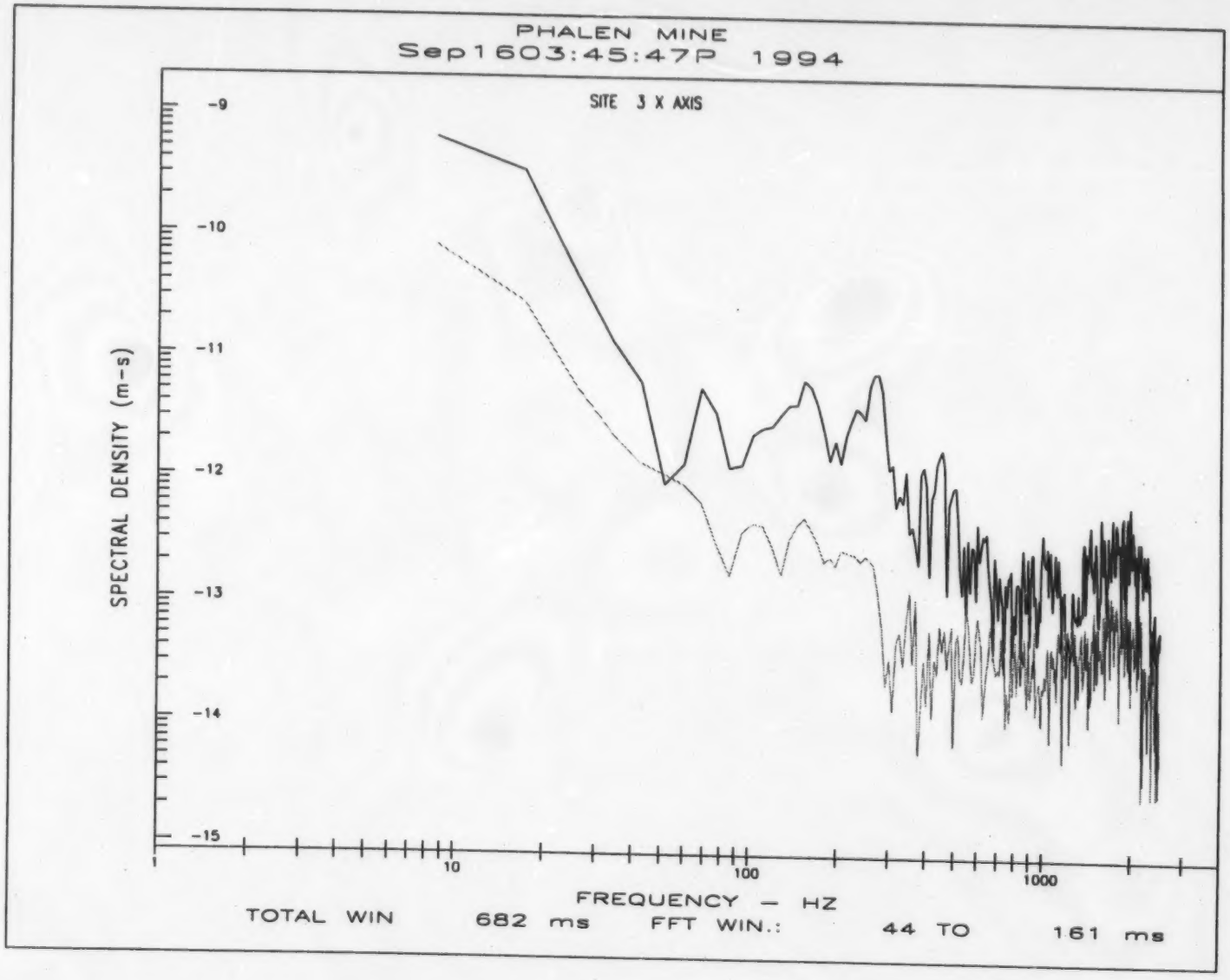

PHALEN MINE
Sep1510:32:19 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+
-
32
0
32
SITE 3X
SITE 3Y
SITE 3Z
0.000
.2
TIME - (SECONDS) TOTAL WINDOW= 369 ms

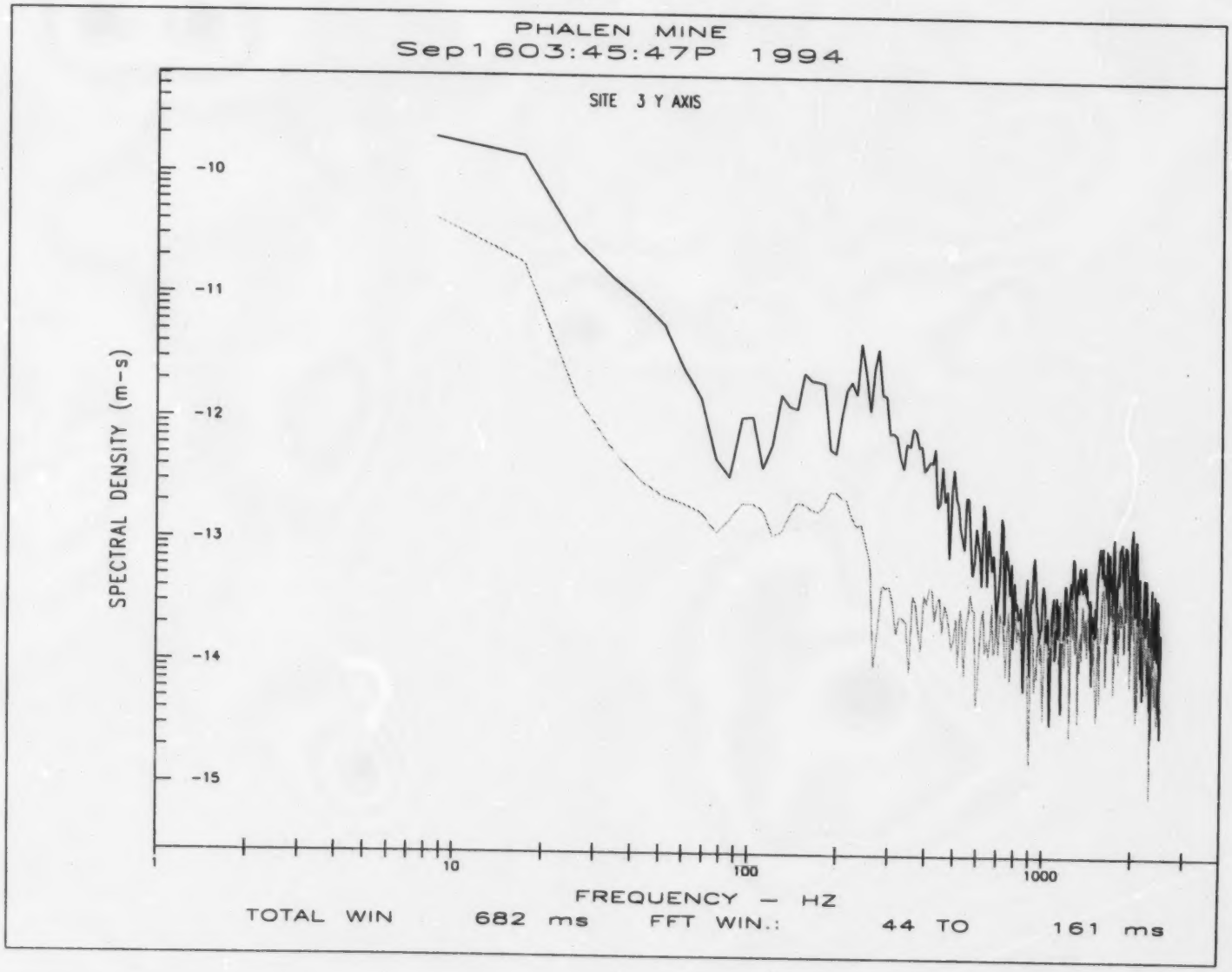

PHALEN MINE
Sep1510:32:19P 1994
SITE 3 X AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 48 TO 201 ms

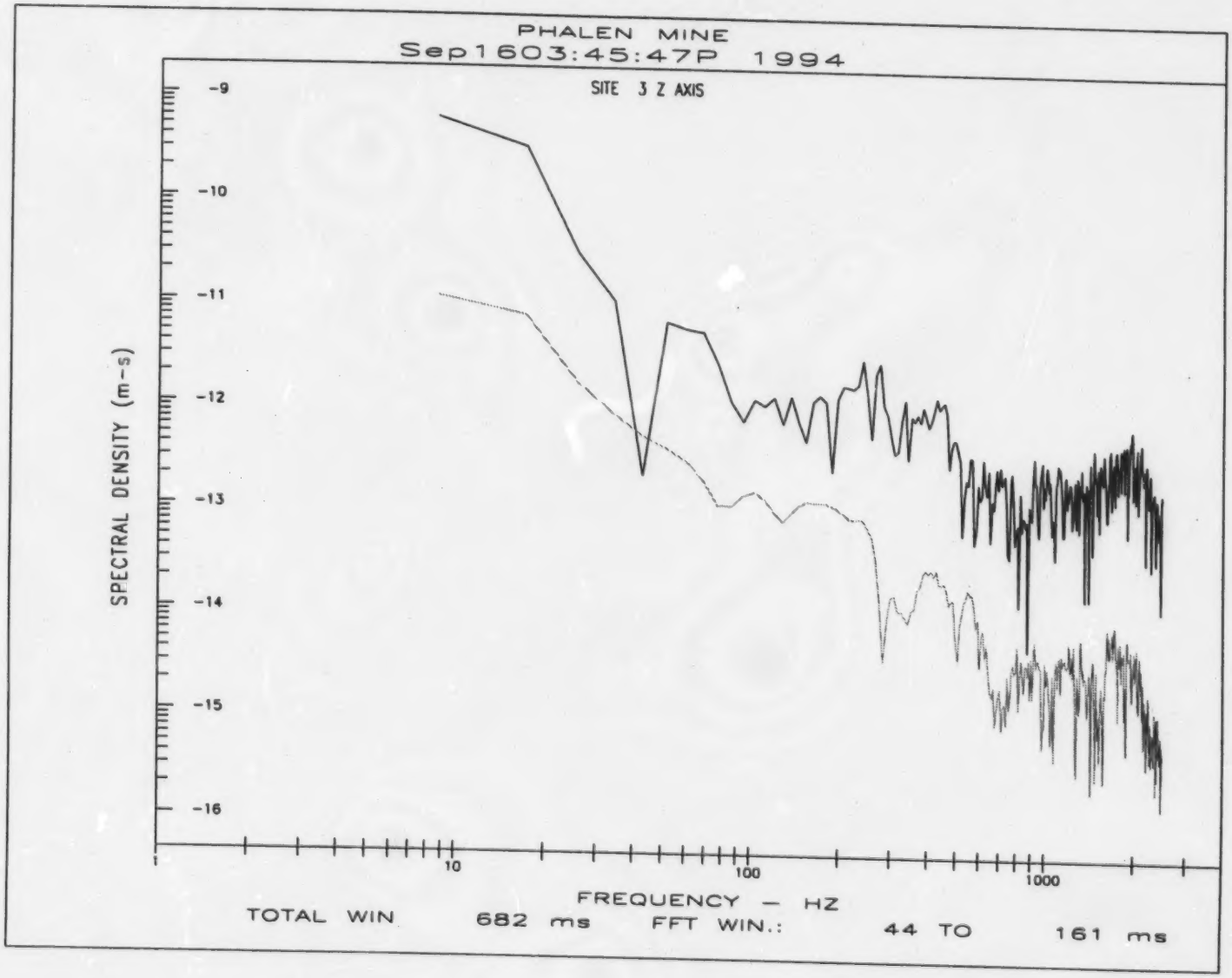

PHALEN MINE
Sep1510:32:19P 1994
SITE 3 Y AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
-16
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 48 TO 201 ms

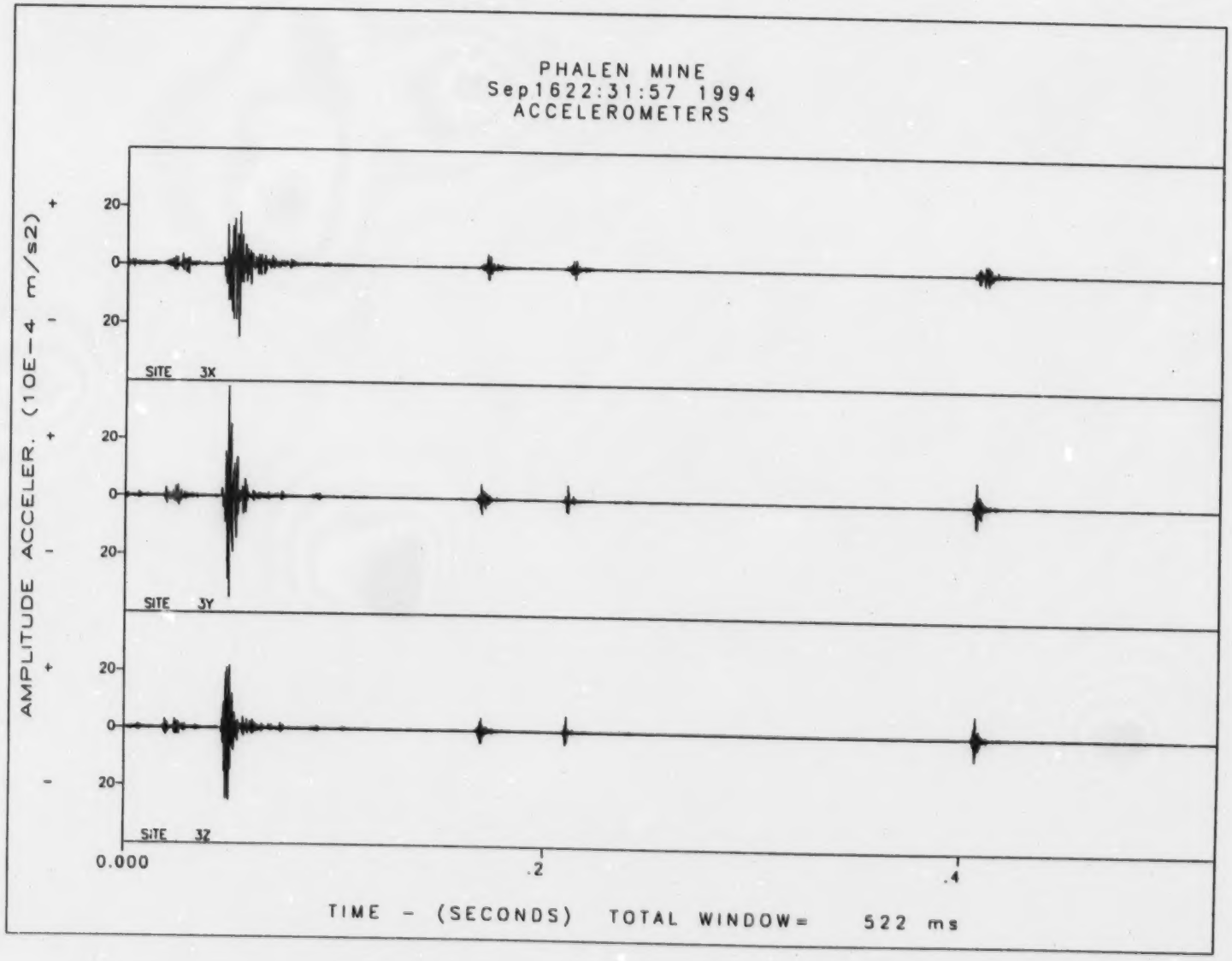

PHALEN MINE
Sep1510:32:19P 1994
SITE 3 Z AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 48 TO 201 ms

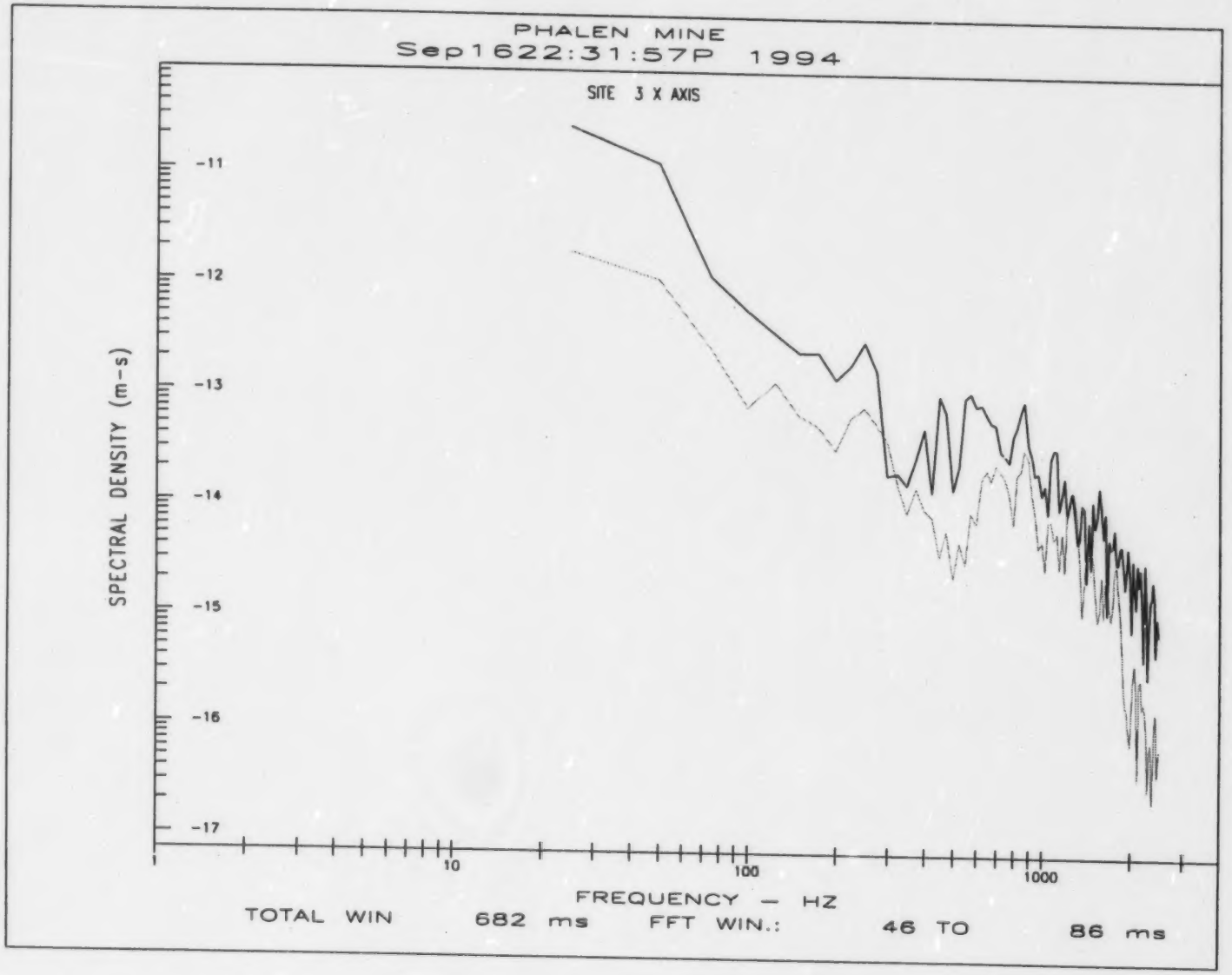

PHALEN MINE
Sep1603:45:47 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
18
0
18
SITE 3X
SITE 3Y
SITE 3Z
0.000
.2
TIME - (SECONDS) TOTAL WINDOW= 304 ms

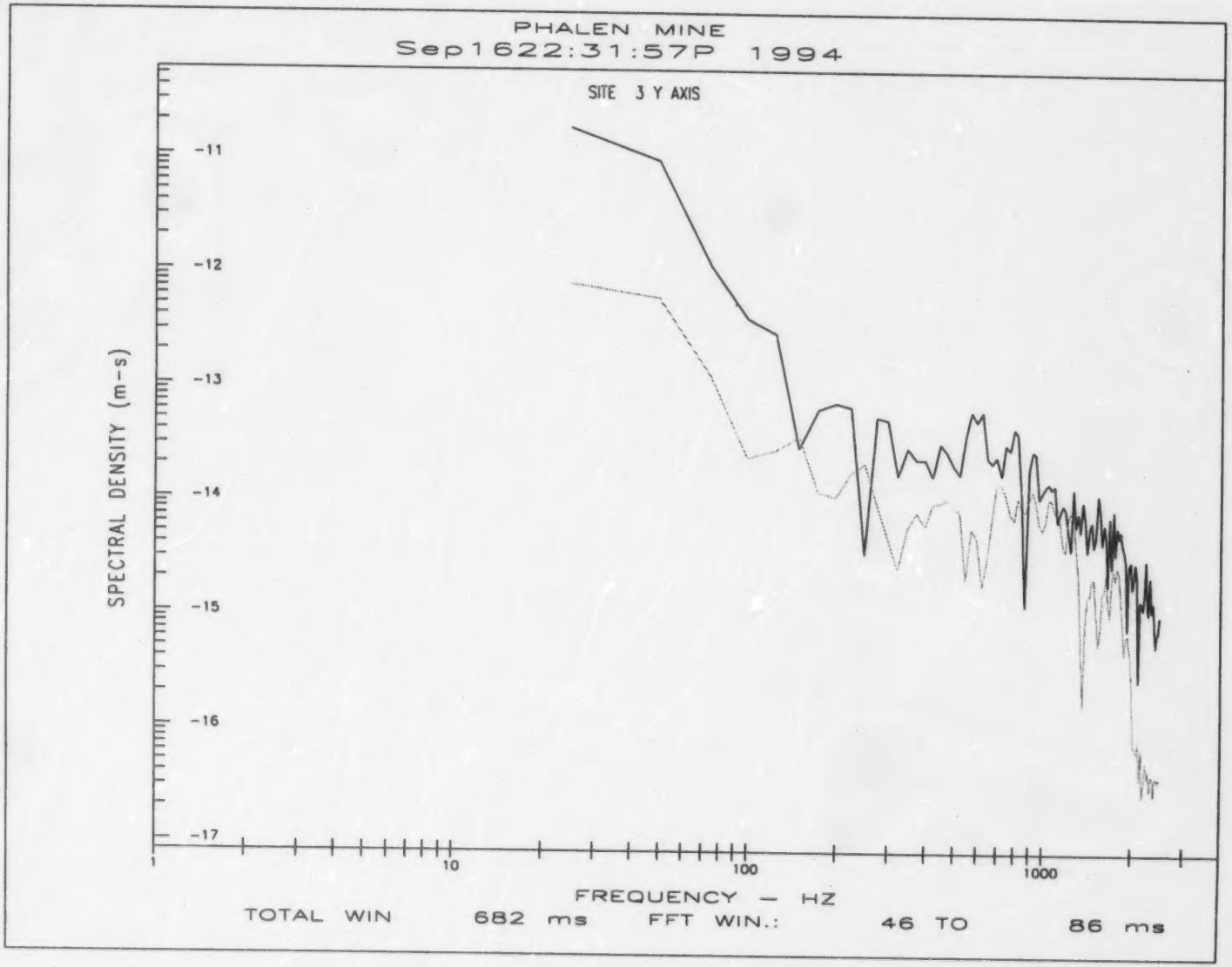

PHALEN MINE
Sep1603:45:47P 1994
SITE 3 X AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 44 TO 161 ms

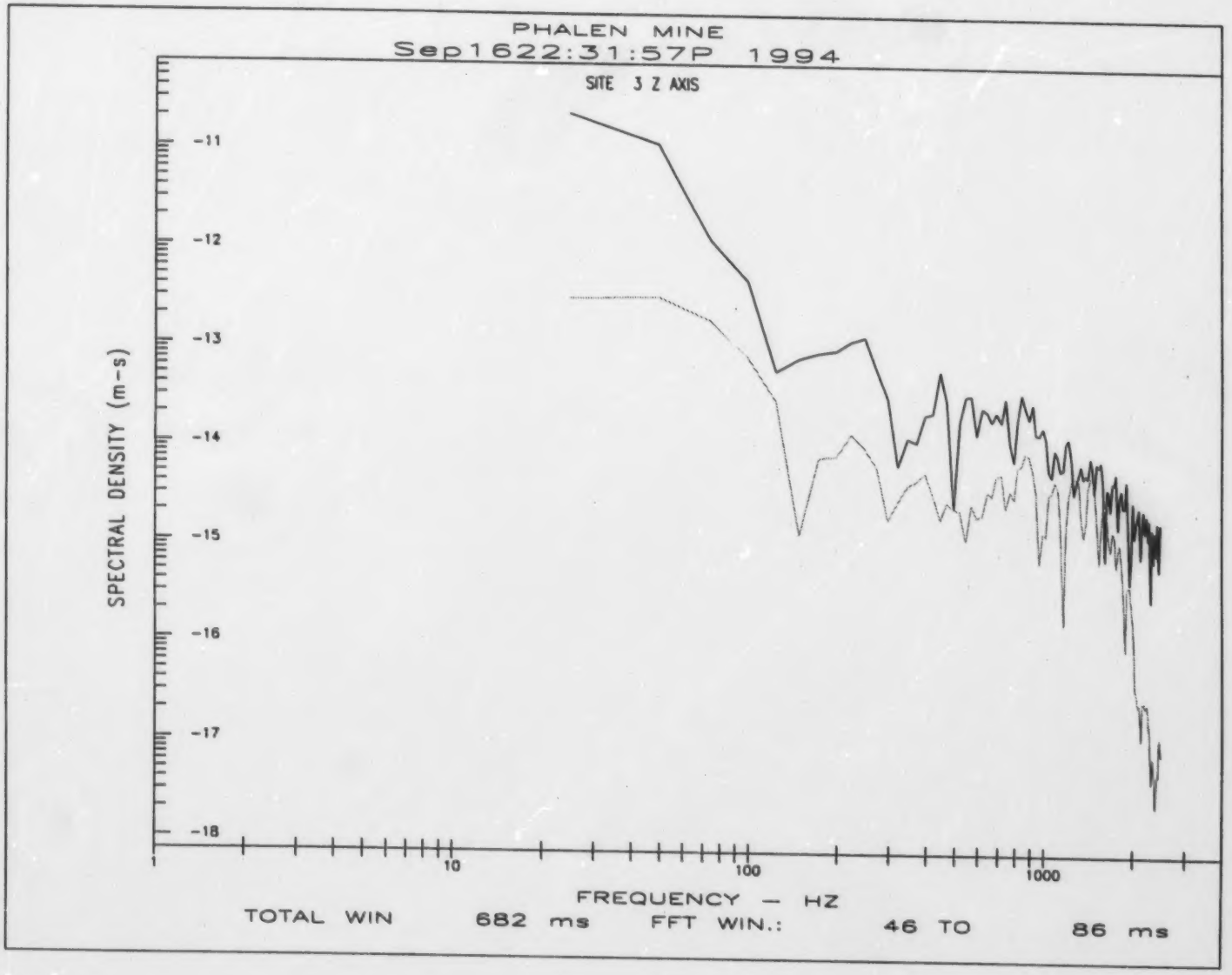

PHALEN MINE
Sep1603:45:47P 1994
SITE 3 Y AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
-15
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 44 TO 161 ms

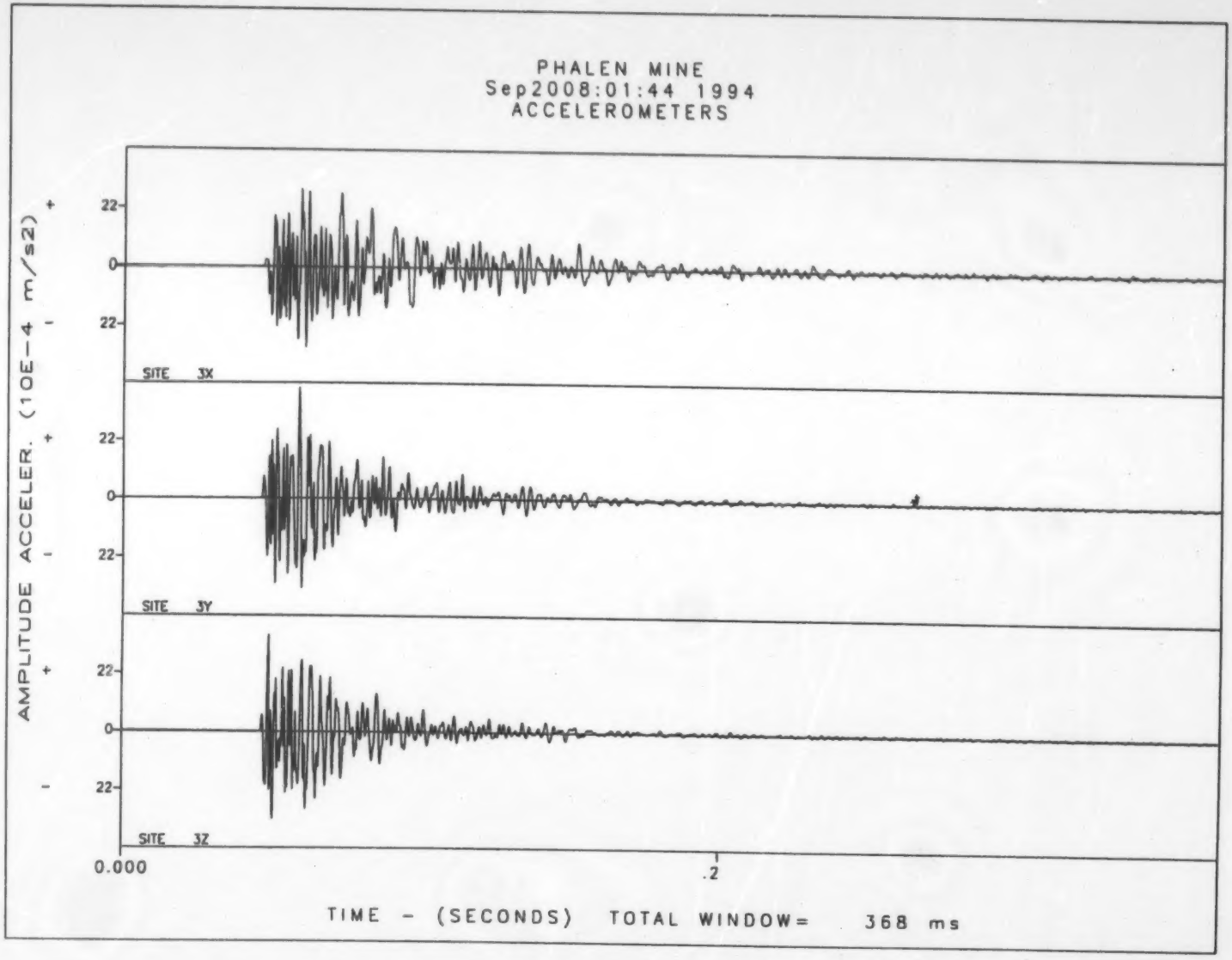

PHALEN MINE
Sep1603:45:47P 1994
SITE 3 Z AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
-16
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 44 TO 161 ms

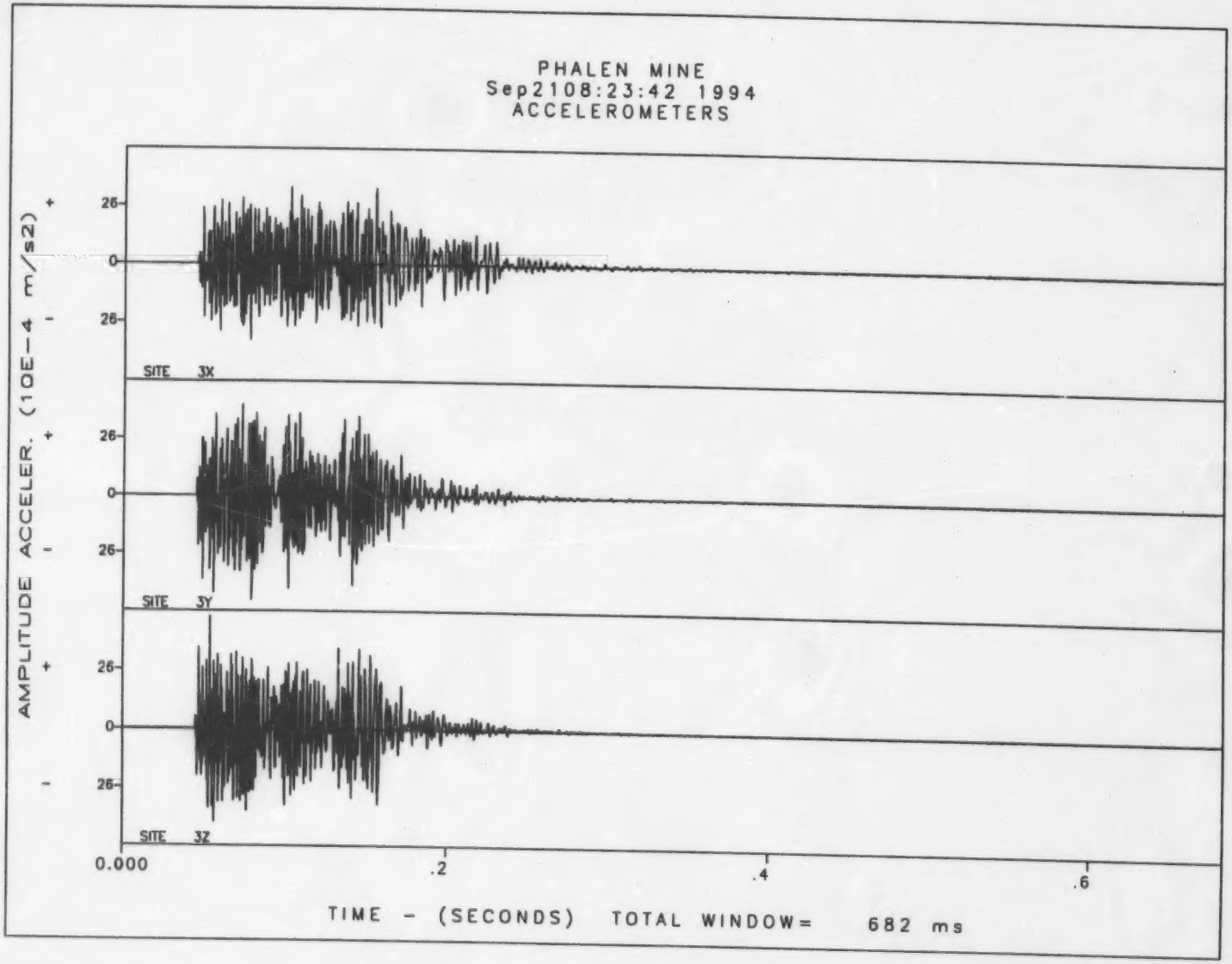

PHALEN MINE
Sep1622:31:57 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
20
0
20
SITE 3X
SITE 3Y
SITE 3Z
0.000
.2
.4
TIME - (SECONDS) TOTAL WINDOW= 522 ms

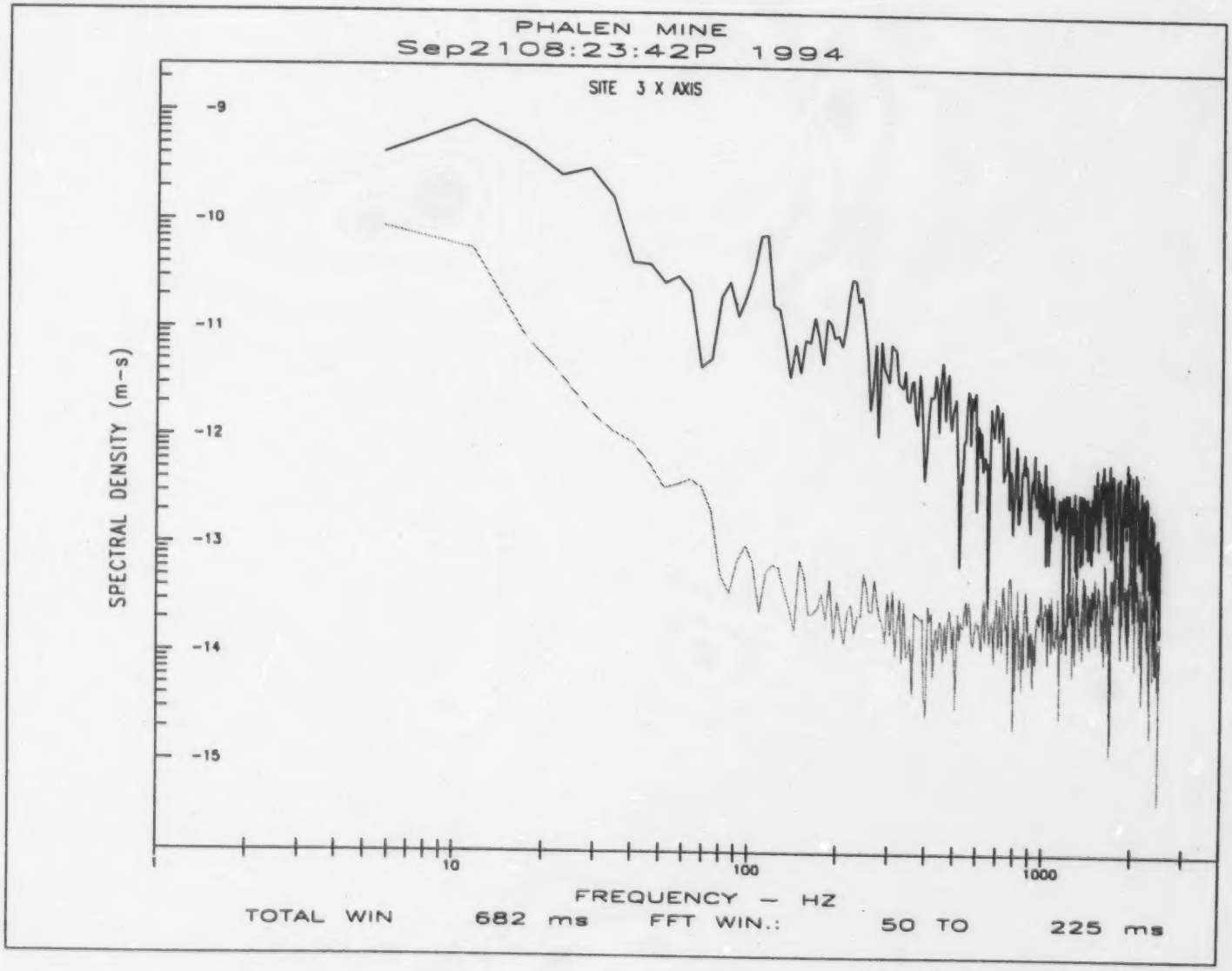

PHALEN MINE
Sep1622:31:57P 1994
SITE 3 X AXIS
SPECTRAL DENSITY (m-s)
-11
-12
-13
-14
-15
-16
-17
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 46 TO 86 ms

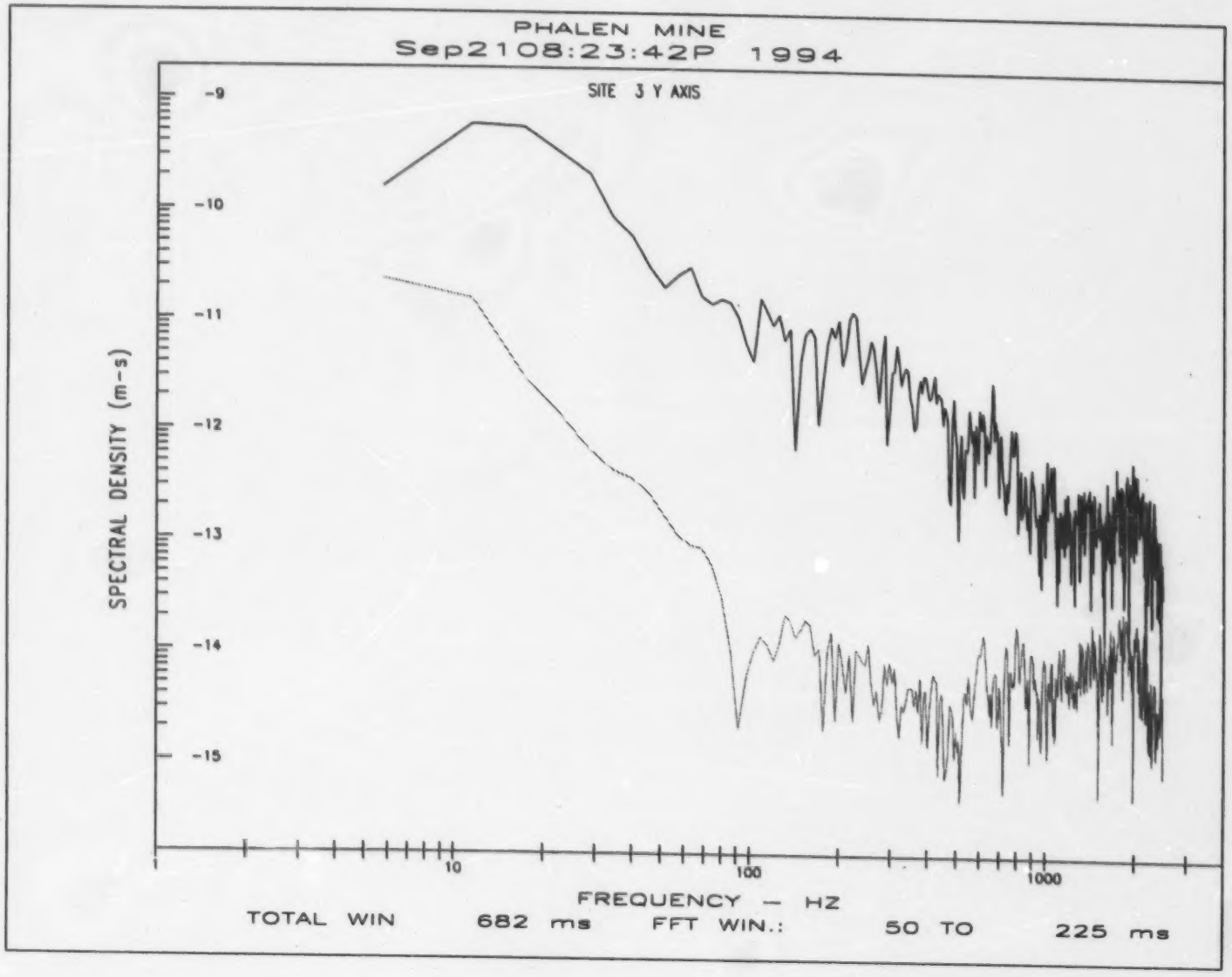

PHALEN MINE
Sep1622:31:57P 1994
SITE 3 Y AXIS
SPECTRAL DENSITY (m-s)
-11
-12
-13
-14
-15
-16
-17
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 46 TO 86 ms

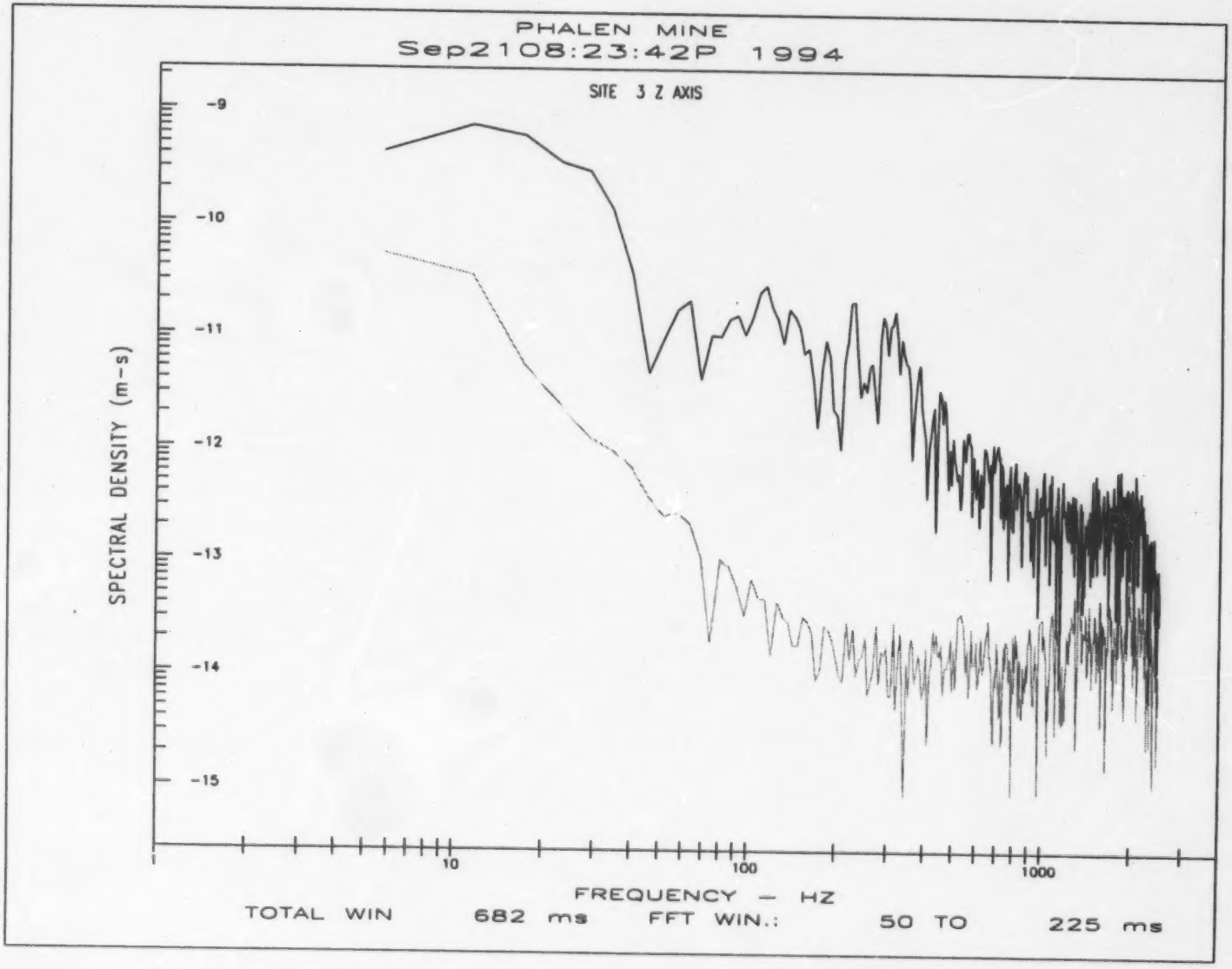

PHALEN MINE
Sep1622:31:57P 1994
SITE 3 Z AXIS
SPECTRAL DENSITY (m-s)
-11
-12
-13
-14
-15
-16
-17
-18
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 46 TO 86 ms

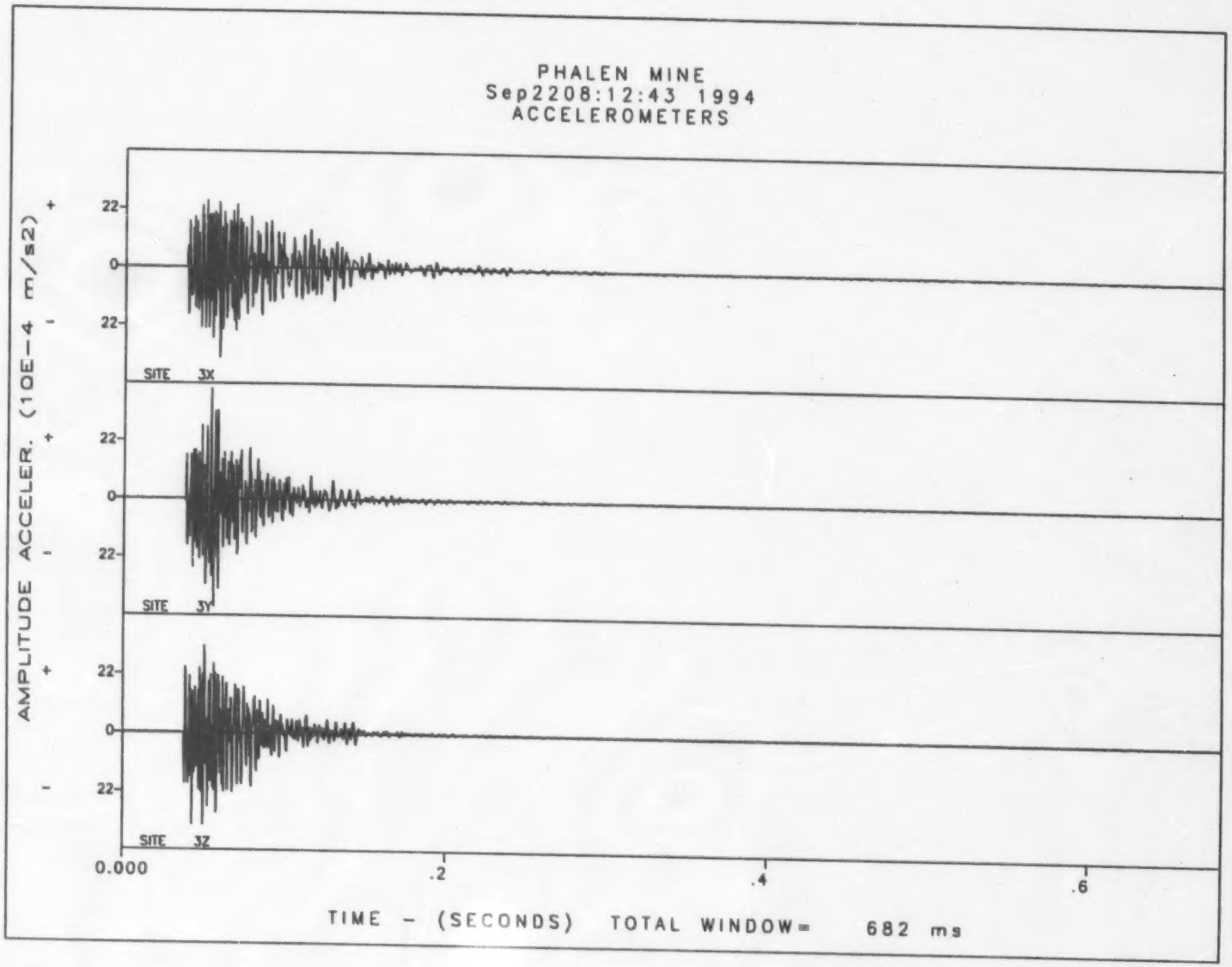

PHALEN MINE
Sep2008:01:44 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
22
0
22
SITE 3X
SITE 3Y
SITE 3Z
0.000
.2
TIME - (SECONDS) TOTAL WINDOW= 368 ms

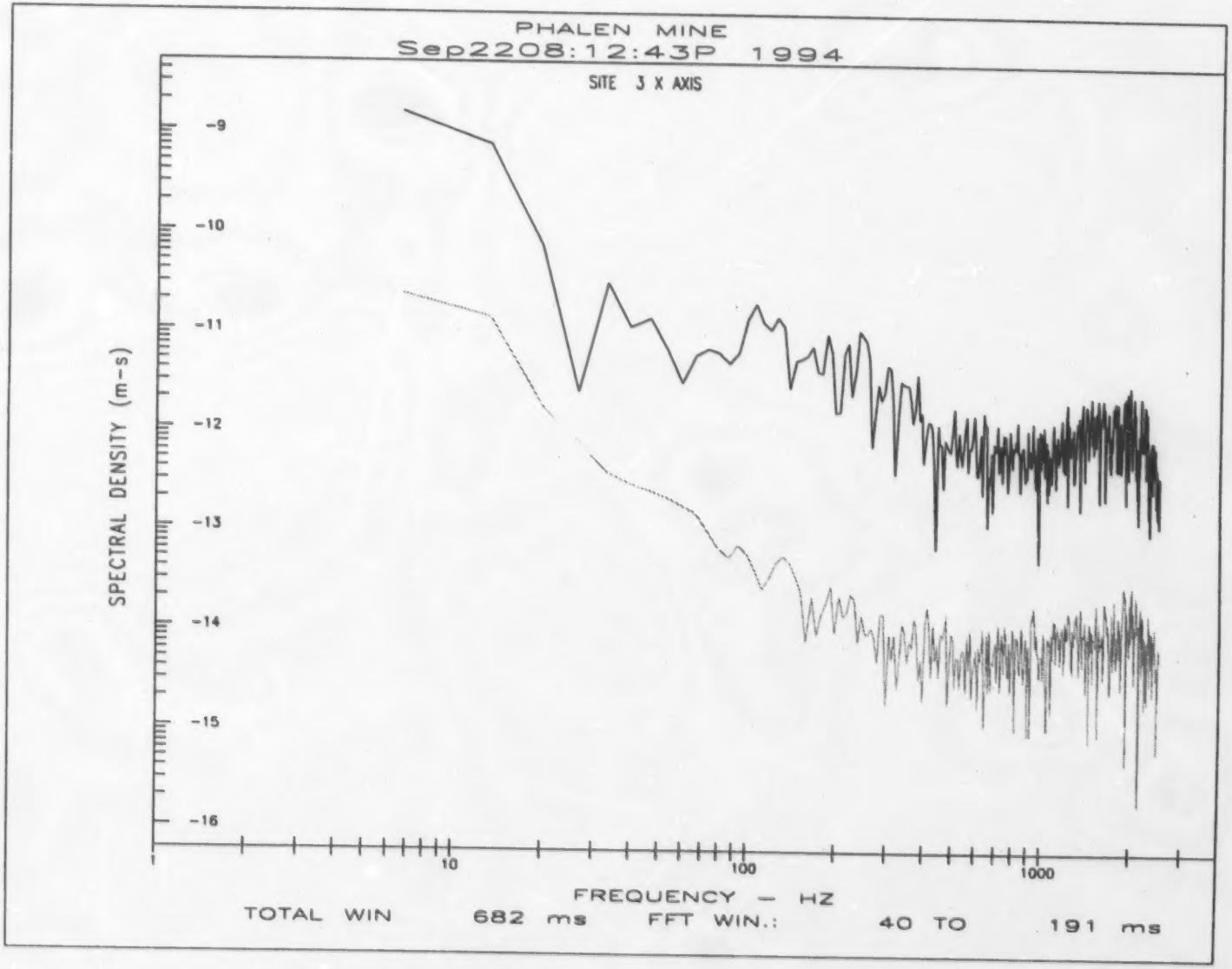

PHALEN MINE
Sep2108:23:42 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+
26
0
26
-
SITE 3X
+
26
0
26
-
SITE 3Y
+
26
0
26
-
SITE 3Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

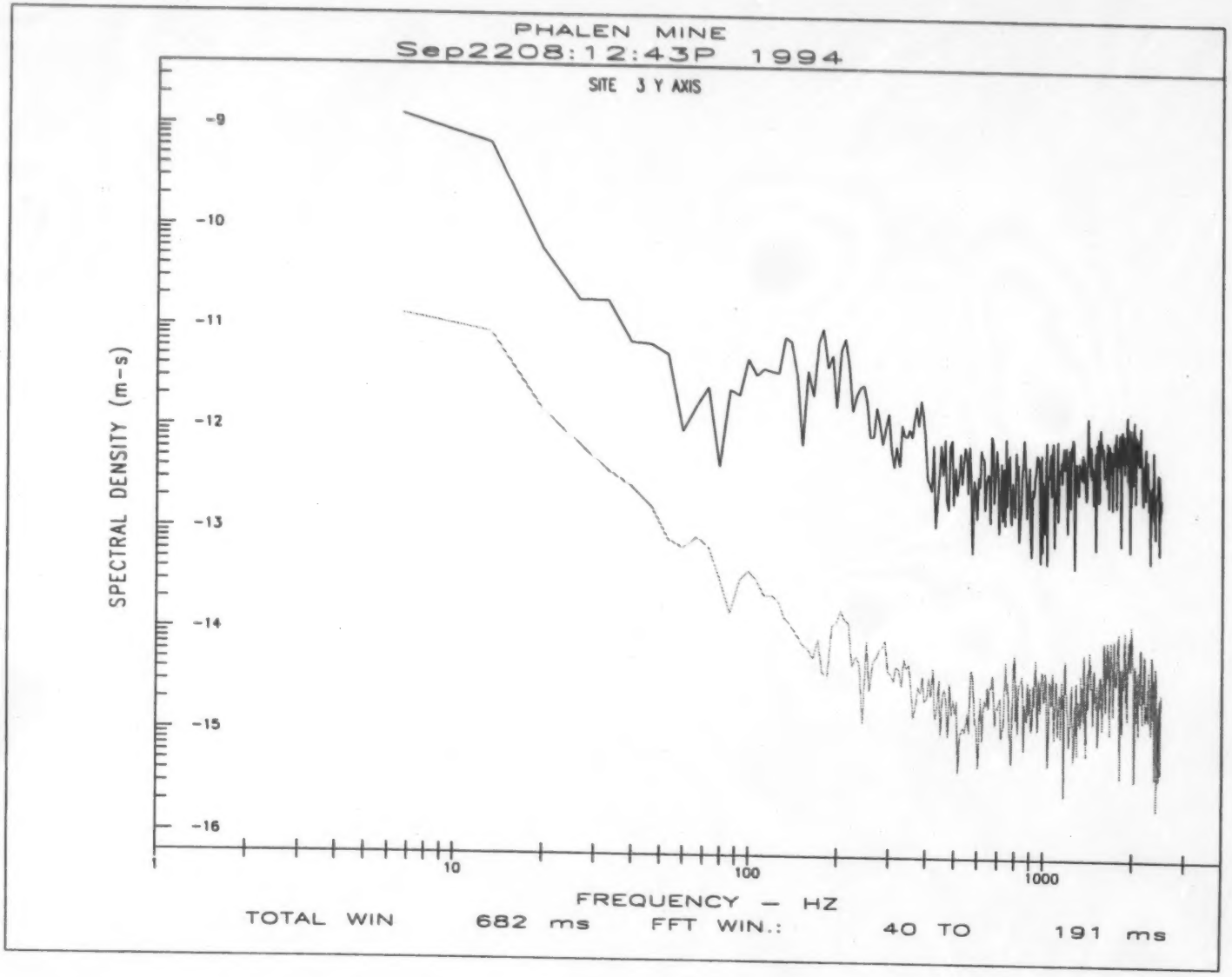

PHALEN MINE
Sep2108:23:42P 1994
SITE 3 X AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 50 TO 225 ms

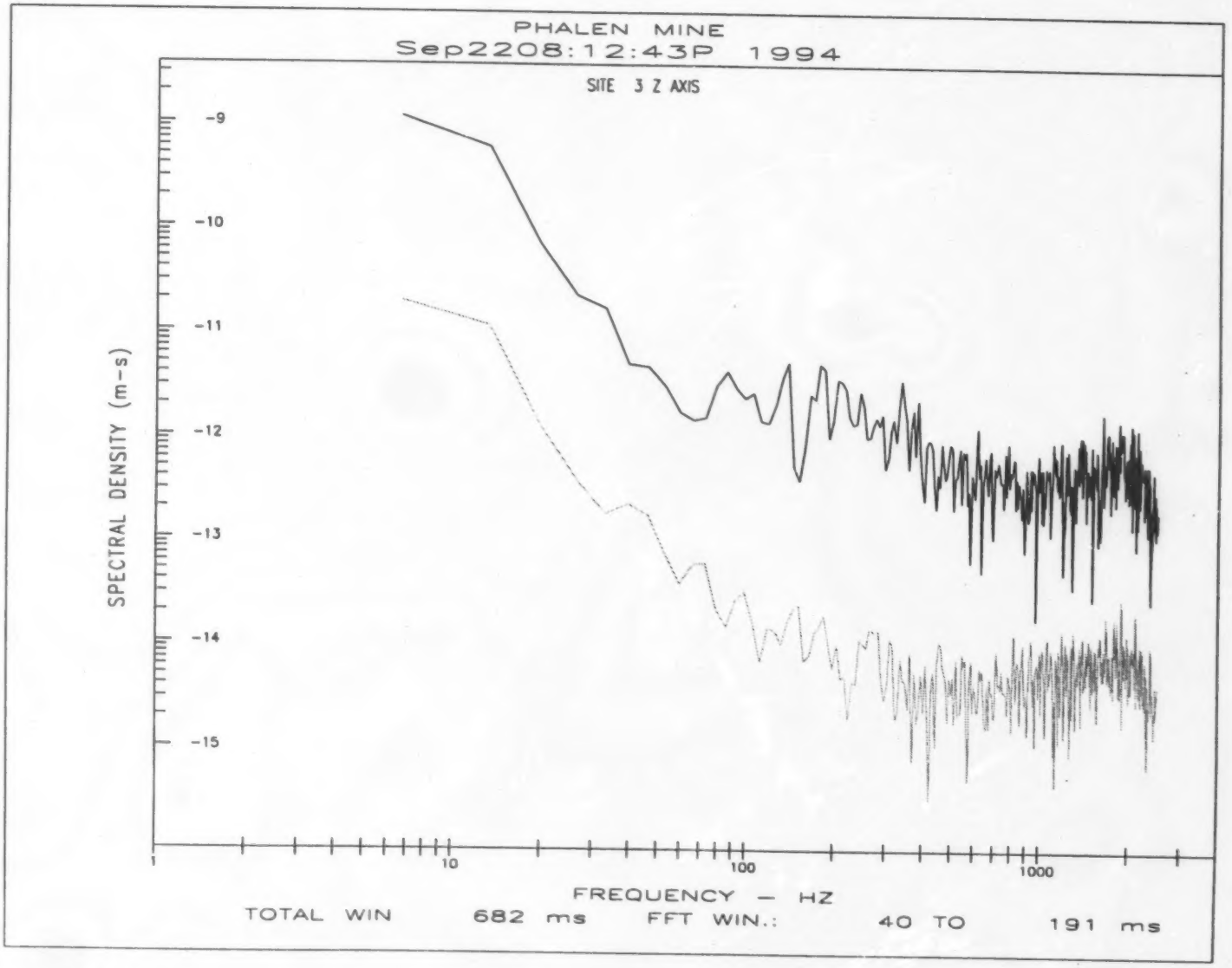

PHALEN MINE
Sep2108:23:42P 1994
SITE 3 Y AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 50 TO 225 ms

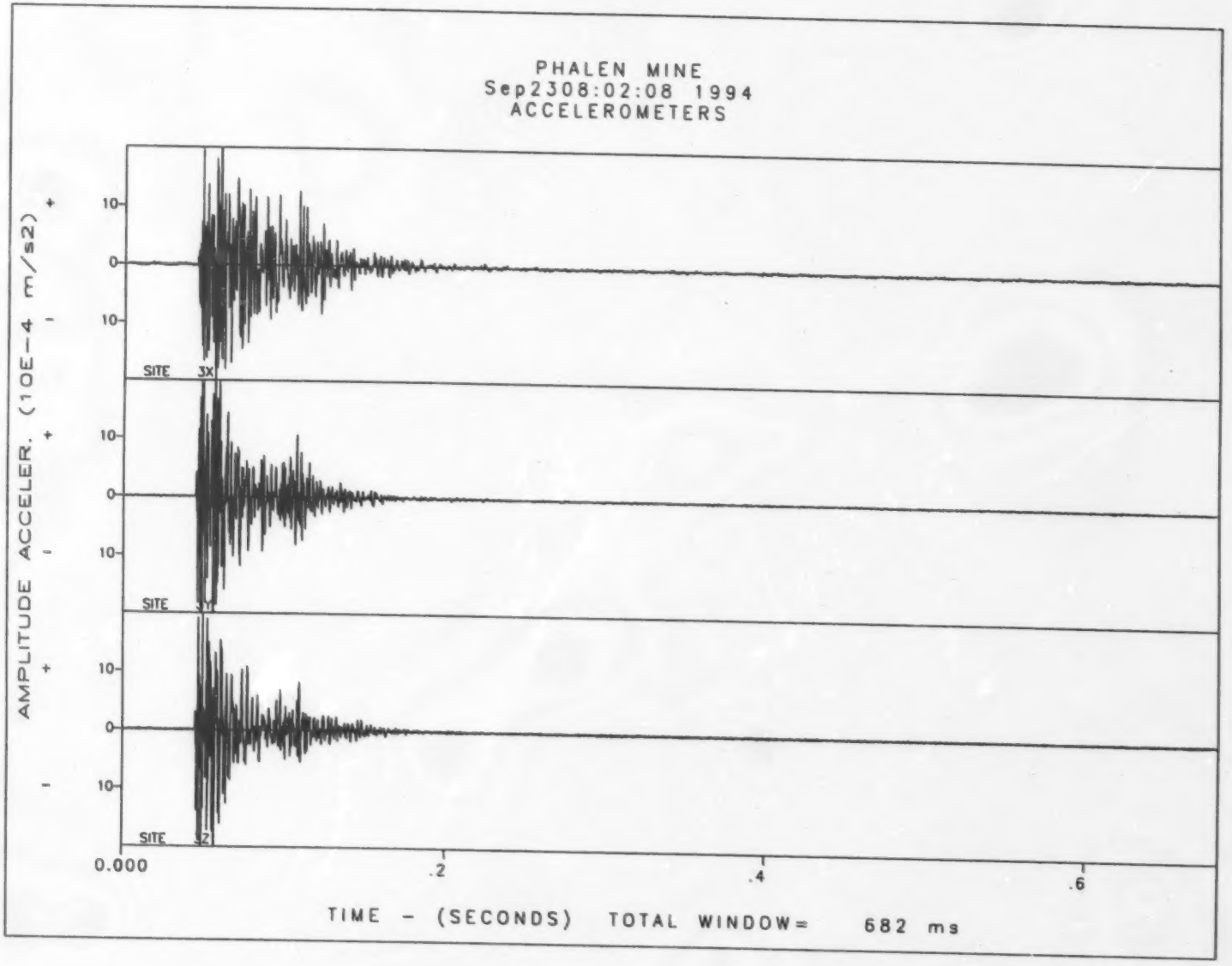

PHALEN MINE
Sep2108:23:42P 1994
SITE 3 Z AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 50 TO 225 ms

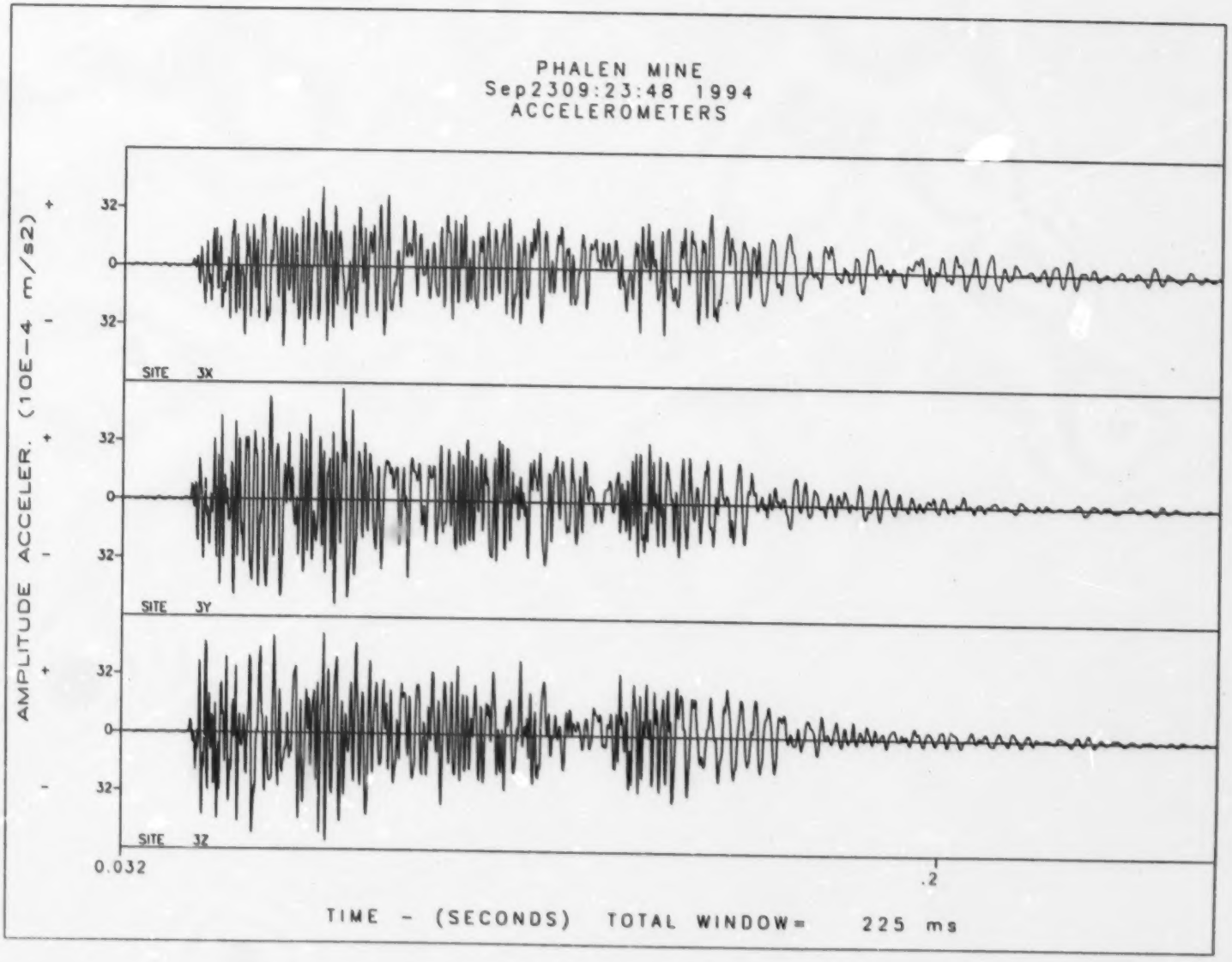

PHALEN MINE
Sep2208:12:43 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
+
-
22
0
22
SITE 3X
SITE 3Y
SITE 3Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

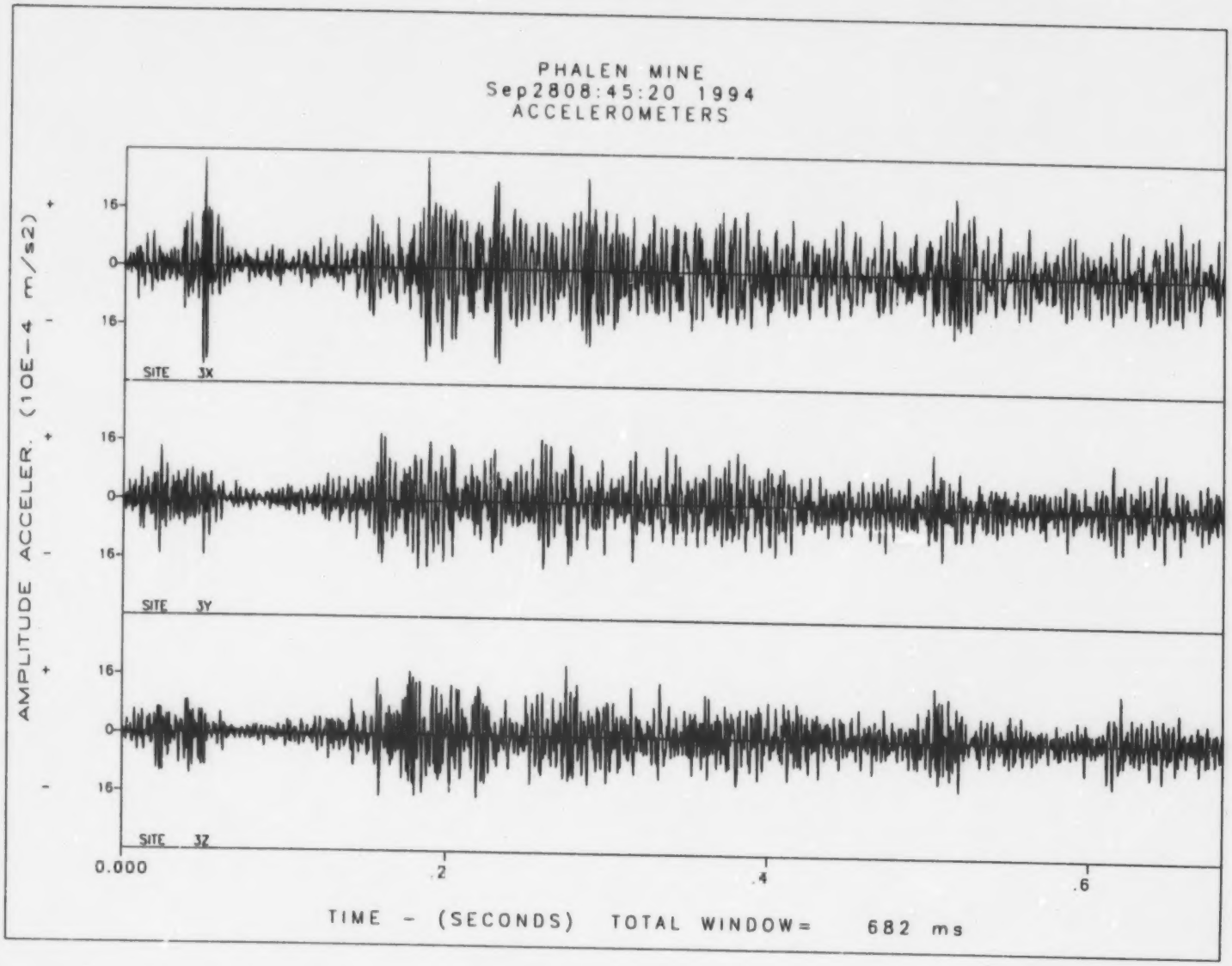

PHALEN MINE
Sep2208:12:43P 1994
SITE J X AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
-16
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 40 TO 191 ms

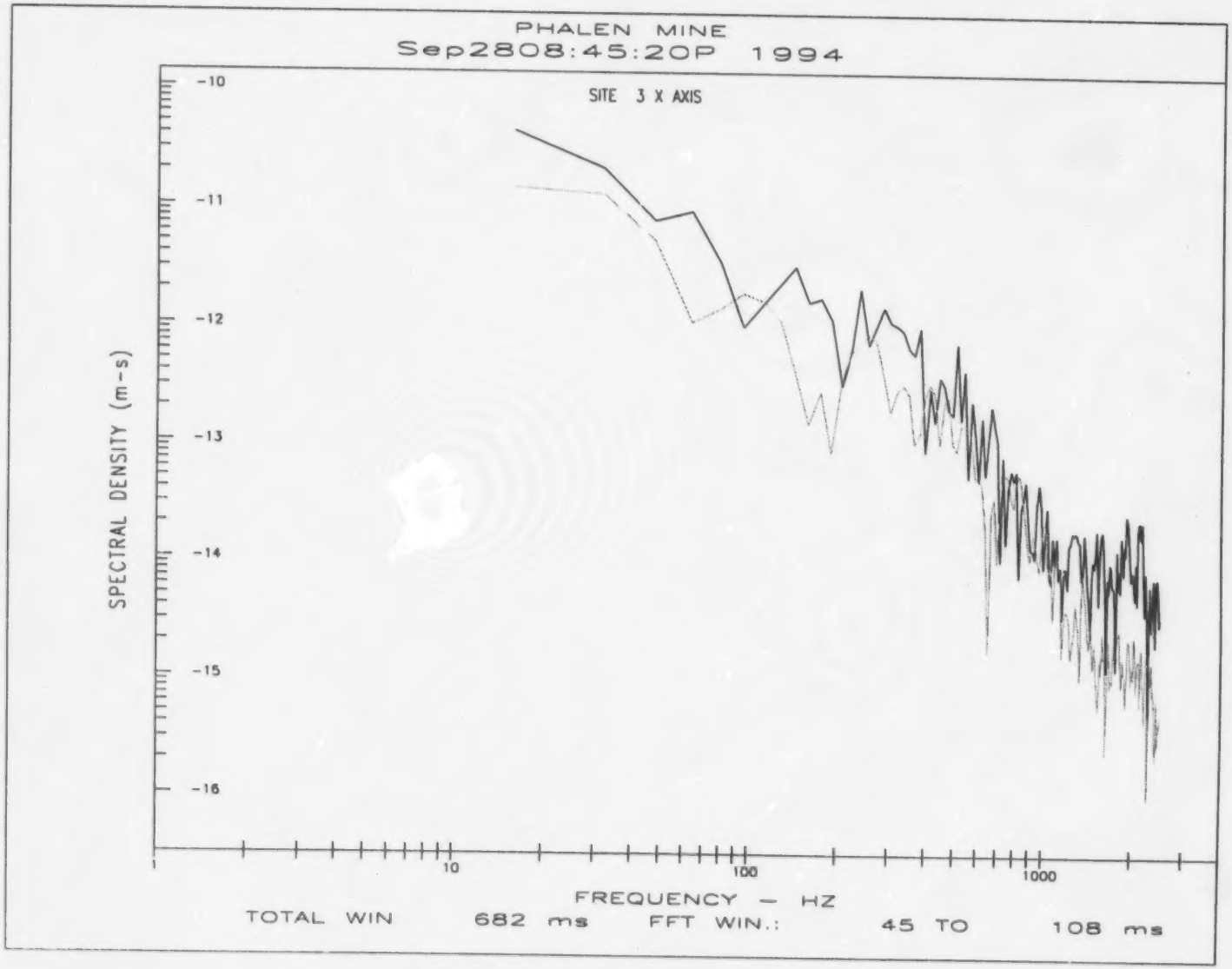

PHALEN MINE
Sep2208:12:43P 1994
SITE 3 Y AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
-16
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 40 TO 191 ms

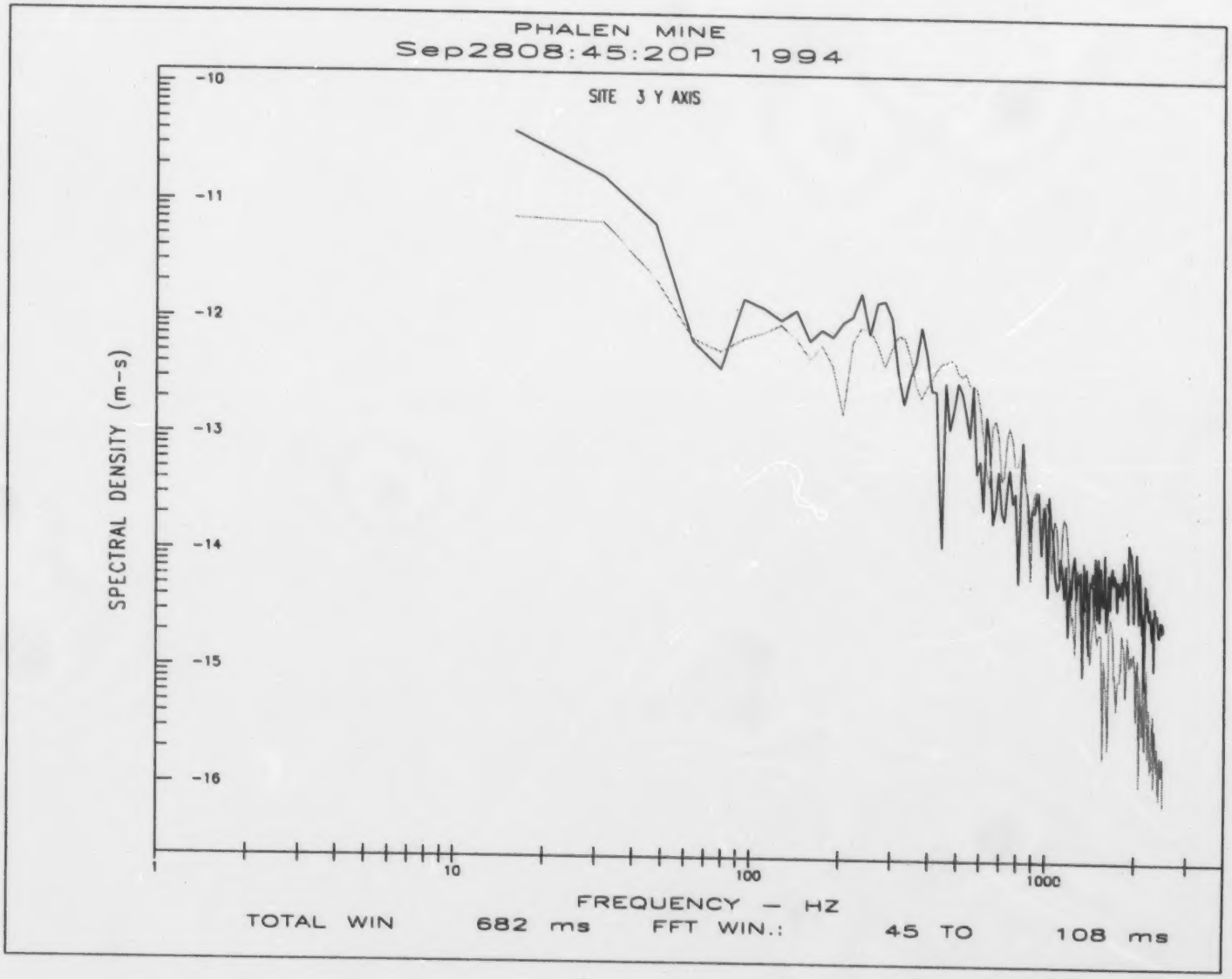

PHALEN MINE
Sep2208:12:43P 1994
SITE 3 Z AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 40 TO 191 ms

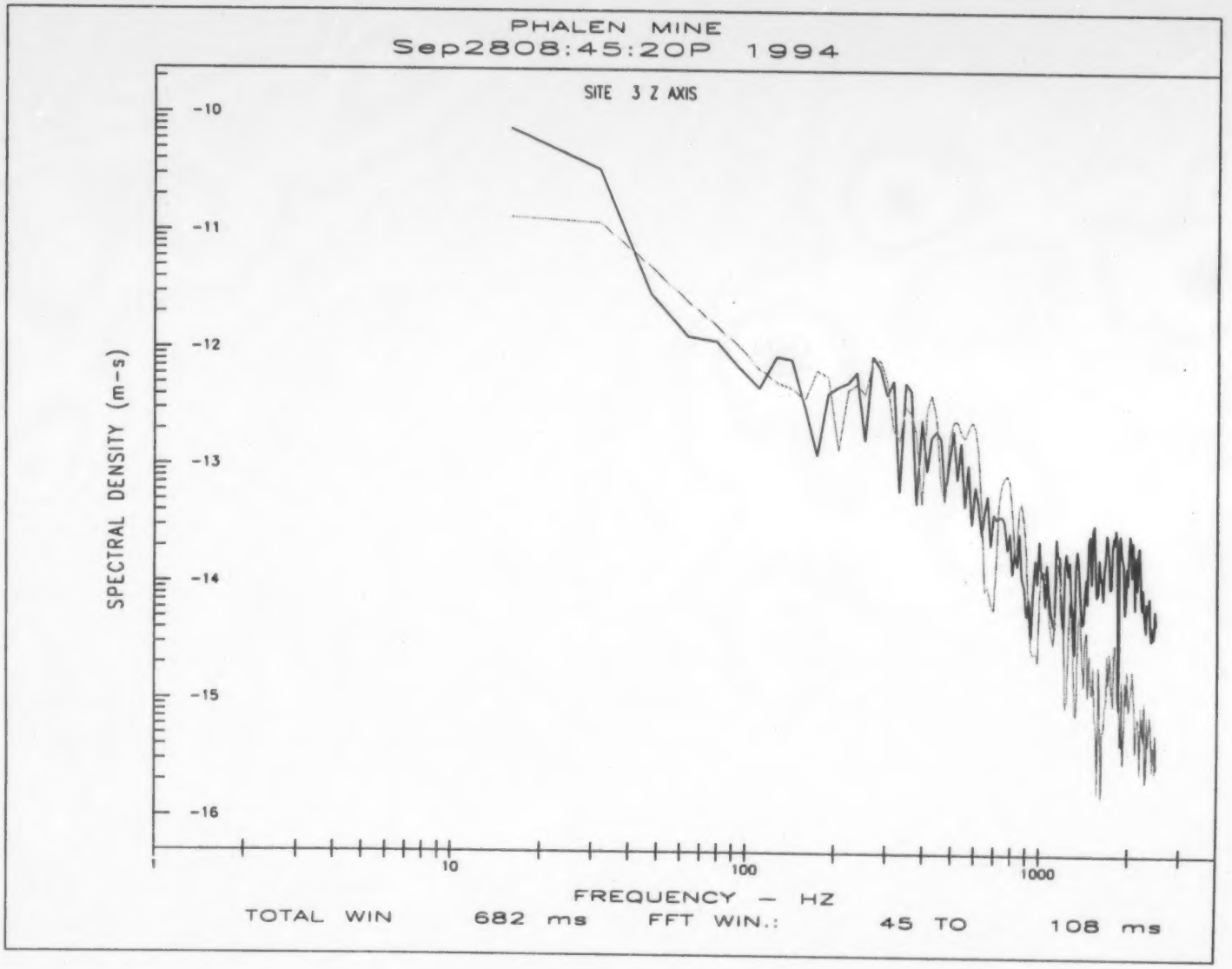

PHALEN MINE
Sep2308:02:08 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
10
0
10
SITE 3X
SITE 3Y
SITE 3Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

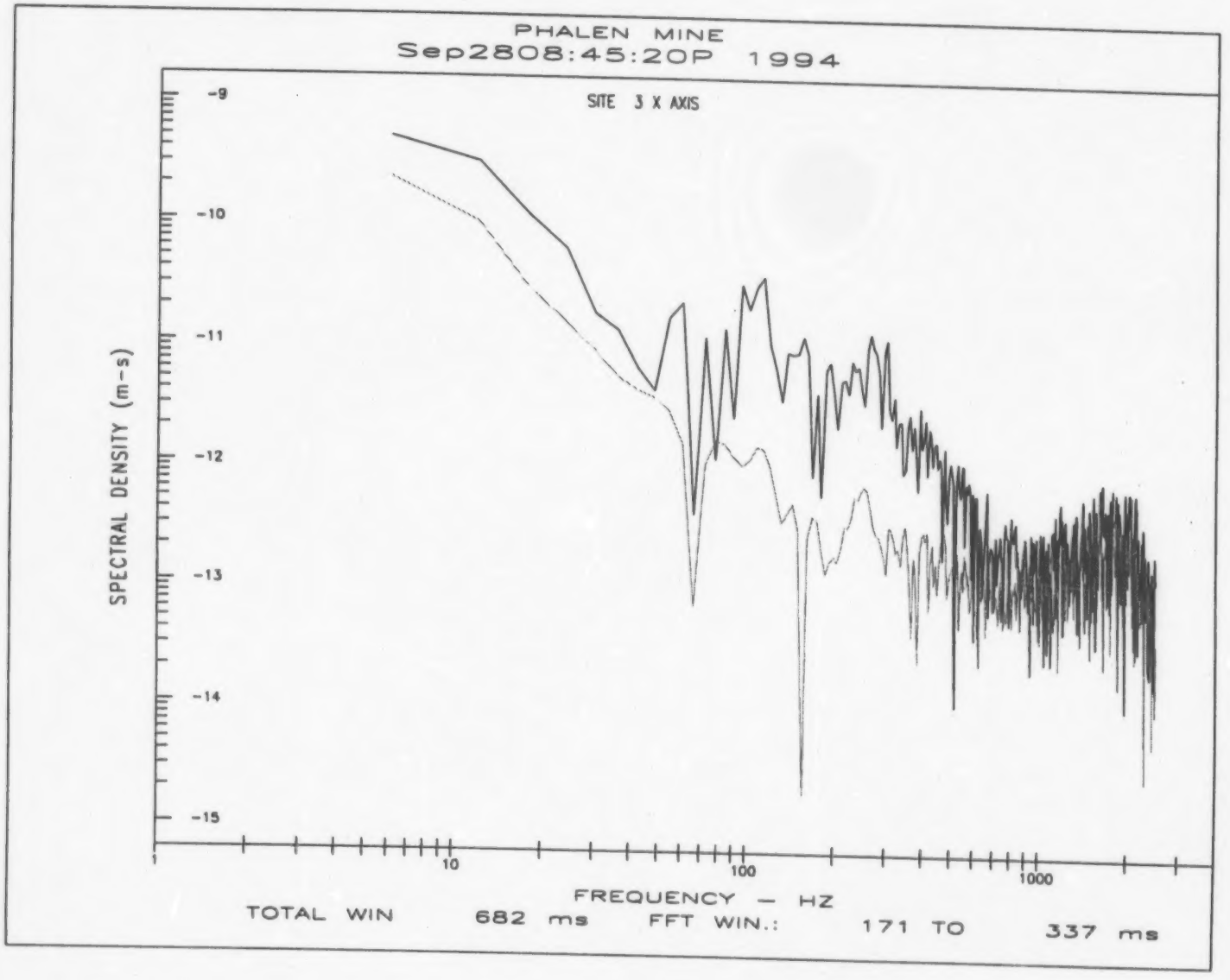

PHALEN MINE
Sep2309:23:48 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
32
0
32
SITE 3X
SITE 3Y
SITE 3Z
0.032
.2
TIME - (SECONDS) TOTAL WINDOW= 225 ms

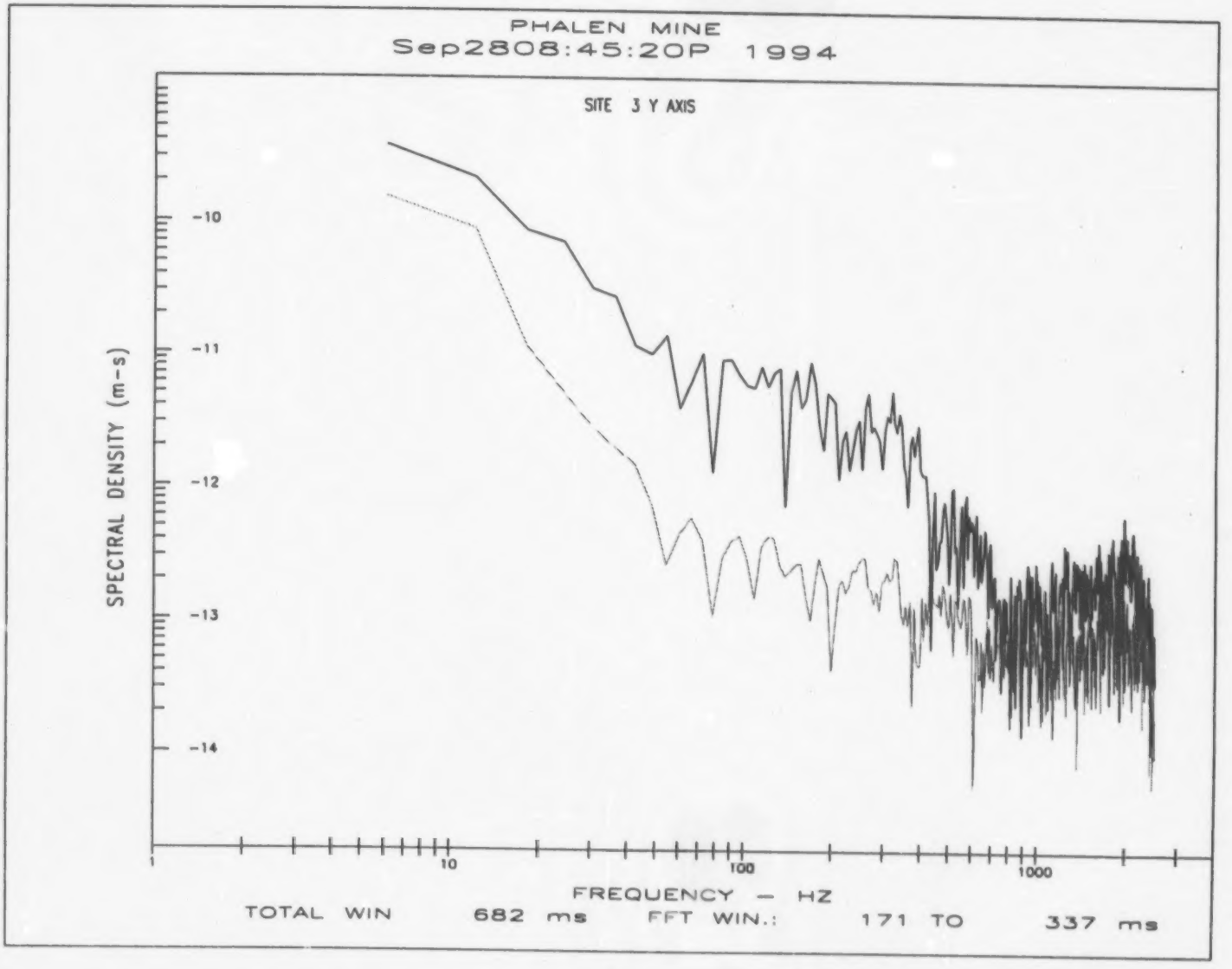

PHALEN MINE
Sep2808:45:20 1994
ACCELEROMETERS
AMPLITUDE ACCELER. (10E-4 m/s2)
16
0
16
SITE 3X
SITE 3Y
SITE 3Z
0.000
.2
.4
.6
TIME - (SECONDS) TOTAL WINDOW= 682 ms

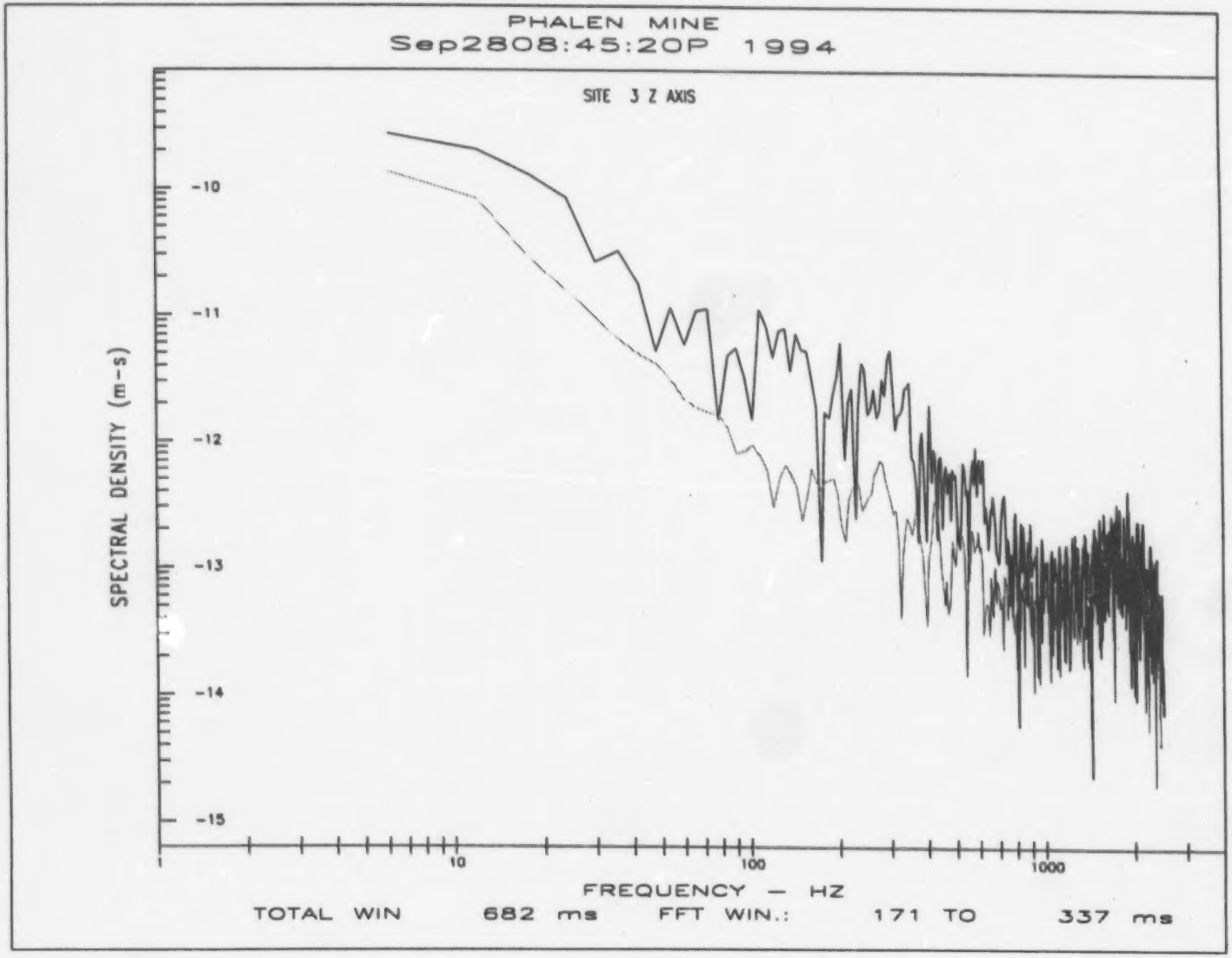

PHALEN MINE
Sep2808:45:20P 1994
SITE 3 X AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
-15
-16
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 45 TO 108 ms


PHALEN MINE
Sep2808:45:20P 1994
SITE 3 Y AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
-15
-16
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 45 TO 108 ms


PHALEN MINE
Sep2808:45:20P 1994
SITE 3 Z AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
-15
-16
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 45 TO 108 ms


PHALEN MINE
Sep2808:45:20P 1994
SITE 3 X AXIS
SPECTRAL DENSITY (m-s)
-9
-10
-11
-12
-13
-14
-15
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 171 TO 337 ms


PHALEN MINE
Sep2808:45:20P 1994
SITE 3 Y AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
1
10
100
1000
FREQUENCY - HZ
TOTAL WIN 682 ms FFT WIN.: 171 TO 337 ms


PHALEN MINE
Sep2808:45:20P 1994
SITE 3 Z AXIS
SPECTRAL DENSITY (m-s)
-10
-11
-12
-13
-14
-15
1
10
100
1000
FREQUENCY — HZ
TOTAL WIN 682 ms FFT WIN.: 171 TO 337 ms